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TECHNICAL ORDER NO. 30-1-9

BASIC TRAINING GUIDE

AIRCRAFT ENGINE FUNDAMENTALS

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Section I. AIRCRAFT ENGINE FUNDAMENTALS

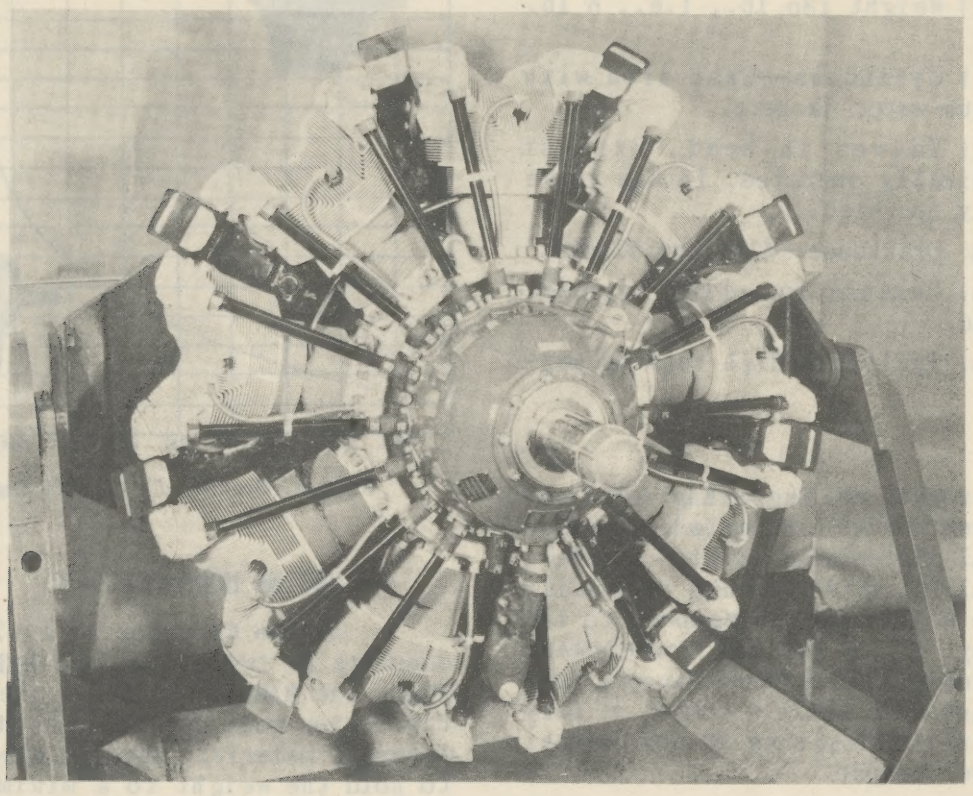


Fig. 1. R-1820 Wright Engine--A Typical Air-cooled Radial Engine.

1. HISTORY OF AIRCRAFT ENGINE POWER.

a. Early experiments with gliders prior to 1900 indicated that the aerodynamics of flight had been coped with to the extent that man-carrying flights were possible and practical. The later experiments of Langley with power-driven models supported this belief. It was, therefore, the lack of a suitable power plant that delayed, to a large extent, the accomplishment of sustained man-carrying flights. The power development, in turn, was dependent largely on the provision of light materials from which to build a satisfactory engine. The commercial development of aluminum greatly aided this cause.

b. The airplane of today is the product of a steady development beginning with the date of the first man-carrying, power-driven airplane, first flown by the Wright Brothers at Kitty Hawk, North Carolina, on December 17, 1903. On this date Orville and Wilbur Wright conducted four successful flights.

c. Today as in the days of the Wright experiments, successful sustained flight depends on power and efficiency of reliable engines. The present aircraft engine is far more powerful, but it also must be maintenanced and overhauled. As the power has increased, engines have become more reliable in proportion and their complexity has increased in direct ratio to the increase in power.

d. One of the greatest difficulties in the way of man's realization of flight was the provision of a satisfactory power plant, light enough, yet with enough tractive power to propel the aircraft at sufficient speed to sustain lift.

e. The first Wright Engine had the following characteristics:

(1) Water cooled
(2) Vertical 4-cylinder type

(3) Bore 4-3/8", stroke 4", displacement 240 cu. in.

(4) 30-35 horsepower at 1200 r. p. m.

(5) Weight 180 lb., i.e., 6 lb. per hp.

(6) Cylinders--Cast iron with sheet aluminum water jackets.

(7) Valves in head. Exhaust valve mechanically operated. Intake valve automatically operated.

(8) Crankcase--Aluminum alloy.

(9) Carburetion--Fuel injected into manifold.

(10) Ignition--High tension magneto.

f. Aeronautical Engine Engineers realized the great weight saving made possible by the radial disposition of the cylinder. With light alloy metals, they gradually cut down the weight per horsepower to the minimum today of 1.2 lb. per horsepower. The liquid-cooled engine manufacturers followed suit and have built a number of very successful in-line engines of low weight and high power output.

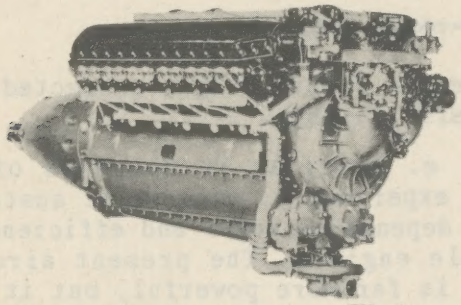


Fig. 2. 3/4 Left Rear View of V-1710-33-- Liquid Cooled V-Type Engine.

g. From this has developed one of the largest branches of the aeronautical industry, the building, maintaining, and overhauling of military and commercial aircraft engines.

h. Fig. 3 shows the growth in engine power from 1923 to 1942. The future under the stress that necessity brings, no man knows. One can feel sure that the growth of engine power will not level off sharply. At this time the industry is striving for greater power than was thought of five years ago.

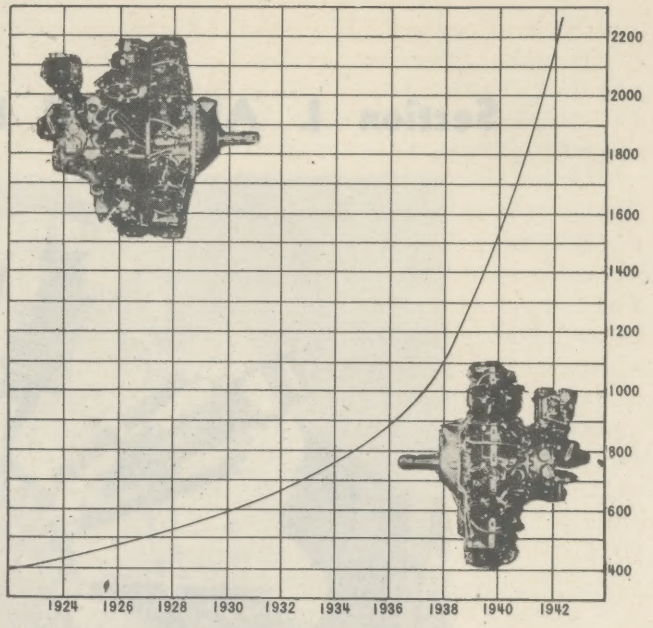


Fig. 3. Growth of Aircraft Engine Power.

2. ENGINE NOMENCLATURE.

a. The Cylinder.--(1) The cylinder consists of two units, the **BARREL** and the **HEAD.** The **BARREL** in which the piston reciprocates must be constructed of high strength material, usually steel, in order to hold the weight to a minimum. It also must have the proper characteristics under high temperatures and must be a good bearing material. The limited space **(THE COMBUSTION CHAMBER)** provided when the piston is at its fullest upward travel is surrounded by an arrangement (usually aluminum alloy) called the **CYLINDER HEAD.** In the combustion chamber the air-fuel mixture (charge) is ignited by the spark plugs and is burned as the piston travels

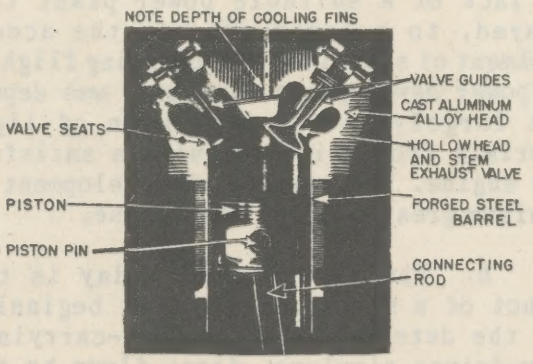
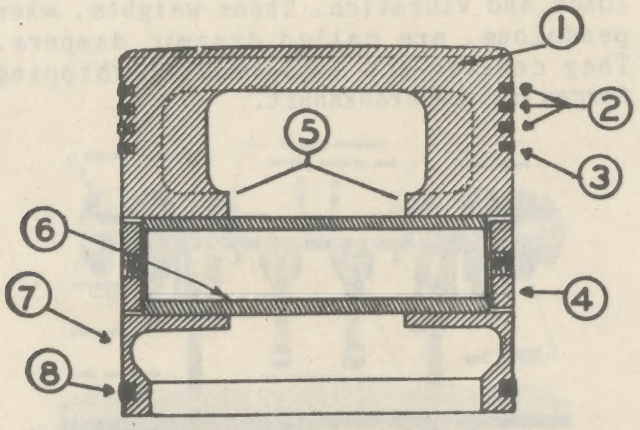


Fig. 4. Typical Radial Engine Cylinder Showing Hollow Exhaust Valve.

toward top center. The ignited charge then expands and drives the piston downward in the cylinder barrel. The head also contains ports in which the intake and the exhaust valves are located.

(2) Each valve port is equipped with a mounting flange to facilitate the attachment of the intake and exhaust manifold systems. The end of the cylinder barrel opposite the head is equipped with a mounting flange for the purpose of attaching the cylinder assembly to the crankcase. The flange is usually so arranged to provide an extension of the cylinder barrel or skirt within the crankcase to restrict the tendency of the oil to flow into it.

b. Pistons.-- (1) The **PISTON** transmits the force of the burning and expanding gases in the cylinder, through the **CONNECTING ROD,** to the engine crankshaft. Pistons are usually made of high-grade aluminum alloy because of its excellent bearing characteristic and high heat conductivity. The underside of the piston head usually contains ribs or other means of presenting more surface for contact with the lubricating oil which is splashed on it. This facilitates piston cooling. Grooves are arranged on its outer surface in order to permit installation of piston rings. These rings are installed between



1. Piston head.
2. Compression rings.
3. Oil control ring.
4. Pin retainer.
5. Piston bosses.
6. Piston pin.
7. Piston skirt.
8. Oil wiper ring

Fig. 5. Typical Piston Assembly.

the aluminum-alloy pistons and the cylinder wall, since due to the difference in the rate of expansion of aluminum, steel, or cast iron, a comparatively large clearance between the piston and cylinder barrels must be provided. The piston rings are usually made of high-grade cast iron. They serve the following purposes: To provide a seal to hold the pressures in the combustion chamber; to retain as much oil as possible in the crankcase; and to conduct heat from the piston head to the cylinder wall.

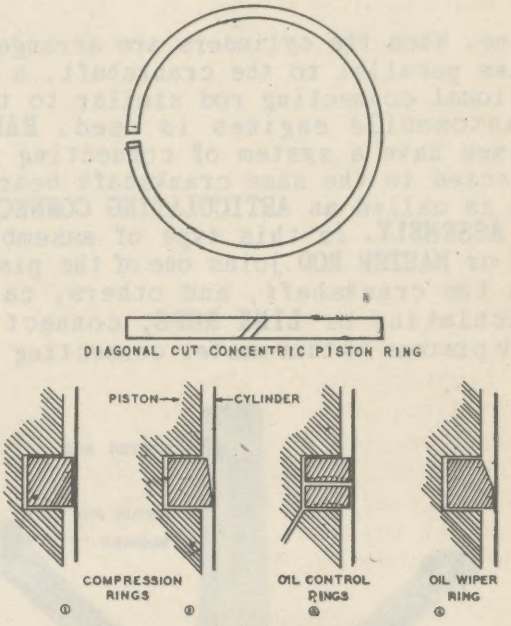


Fig. 6. Cross-section of Piston Rings.

(2) A steel piston **PIN** passes through the piston at right angles to the skirt for the purpose of anchoring the piston to the connecting rod assembly. Provision is made for retaining the piston pin so that it will not move sideways and scratch or score the cylinder walls.

c. Connecting Rods --The connecting rods furnish means of converting the reciprocating motion of the piston to a rotating movement of the crankshaft in order to drive the propeller. These units must of necessity be made of high-grade steel properly designed and constructed. The small end attached to the piston usually has a bronze-alloy insert bushing having good bearing characteristics. The crankshaft end is usually split to provide for assembly. This end contains bearing **SHELLS** or **LINERS** and is held in place by bolts. The type of connecting rod will depend somewhat on the cylinder arrangement of the

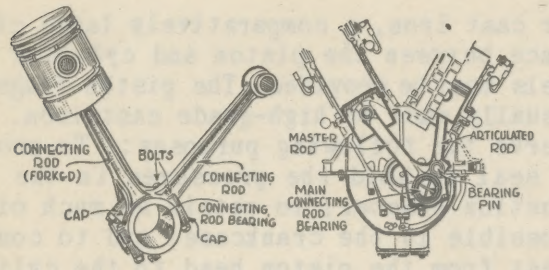


Fig. 7. Clevis, or Forked, and Articulated Connecting Rods.

engine. When the cylinders are arranged in a line parallel to the crankshaft, a conventional connecting rod similar to those in automobile engines is used. **RADIAL** engines have a system of connecting rods connected to the same crankshaft bearing. This is called an **ARTICULATING CONNECTING ROD ASSEMBLY.** In this type of assembly a **MAIN** or **MASTER ROD** joins one of the pistons with the crankshaft, and others, called articulating or **LINK RODS,** connect the other pistons to this master connecting rod.

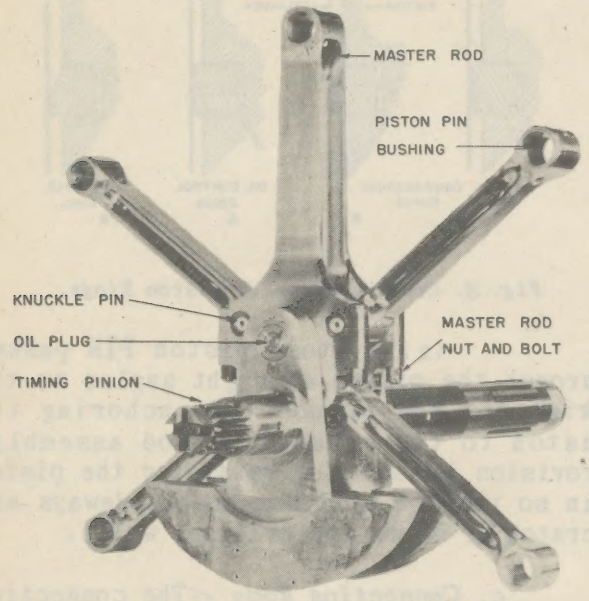


Fig. 8. Solid-Type Radial Engine Crankshaft and Split Big-End Master Rod.

d. Crankshaft.--(1) The crankshaft converts the force from the power stroke of the pistons into rotational force called **TORQUE** which turns the propeller. The crankshaft is usually hollow in order to reduce weight and provide a means of circulating lubricating oil in the engine. This is discussed later under **LUBRICATION SYSTEM.** Since the crankshaft is stressed highly, it must be made of the very best materials and must be designed well and constructed accurately. It is built with a front shank on which the propeller is mounted in a direct drive engine. The crankshaft is held in place by a **RADIAL BALL THRUST BEARING** properly secured in both the case and on the shaft itself. The thrust bearing is loaded with **CENTRIFUGAL, GYROSCOPIC,** and **THRUST FORCES** developed by the engine and propeller combination. The **CRANK ARM** or **THROW** is the part by which the reciprocation of the piston and its stroke or travel is governed. The section on which the connecting rod operates is called the **CONNECTING ROD BEARING JOURNAL.**

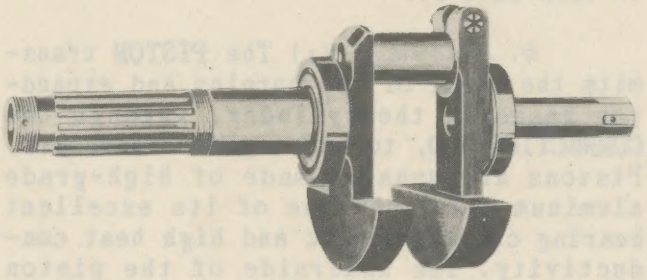


Fig. 9. Radial Engine Crankshaft.

(2) Opposite the throw a counterweight arrangement is usually found, the purpose of which is to balance the weight of the reciprocating and other forces in order to reduce main bearing loads and vibration. These weights, when pendulous, are called dynamic dampers. They counter-act torsional or whipping forces in the crankshaft.

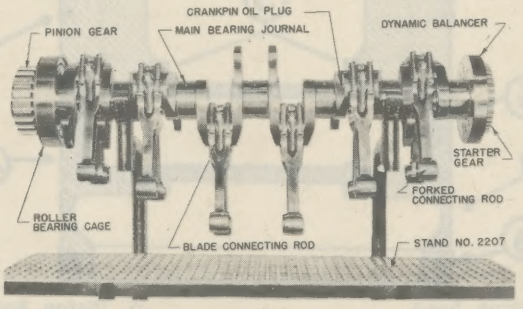
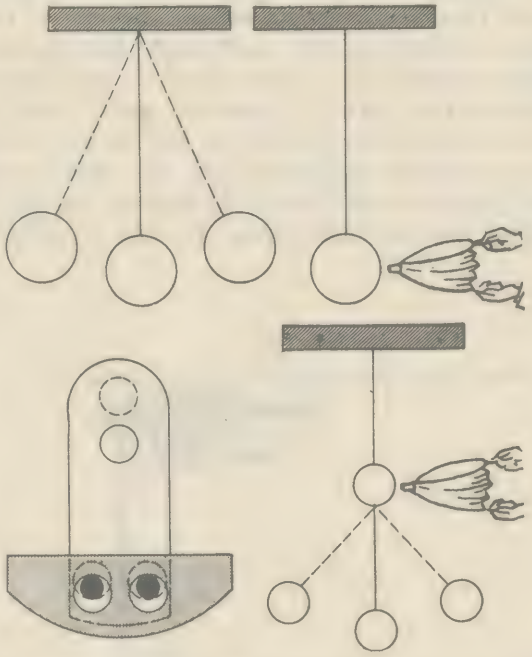


Fig. 10. Crankshaft of the Allison V-1710 Engine.

(3) The rear shank or extension furnishes a means of driving the supercharger, magnetos, generators, oil pumps, and other accessories necessary to the proper functioning of the power plant.

(4) Provision is made in the crankcase sections for supporting the crankshaft adjacent to the throws by the installation of main bearings. The valve actuating mechanism, for opening and closing valves to permit entrance of fresh mixture and the discharge of burned gases, is usually driven off either the front or rear shank by means of a gear train.

Fig. 11. Principle of the Dynamic Damper.



If a simple pendulum were given a series of regular impulses at a speed corresponding to its natural frequency (using a bellows to simulate a modified power impulse in an engine), it would commence swinging or vibrating back and forth from the impulses.

Another pendulum, suspended from the first, would absorb the impulse and swing itself, leaving the first one stationary. The DYNAMIC DAMPER is a short pendulum hung on the crankshaft and tuned to the frequency of the power impulse to absorb vibration in the same manner.

e. Crankcase.--The **CRANKCASE** is a housing which encloses the various mechanisms surrounding the crankshaft. The cylinders and external accessories are attached to it. This housing must be oil tight and provided with a **BREATHER** system to relieve the rapidly changing pressures within. A chamber, called a **SUMP**, is sometimes provided on the lower side of the crankcase to collect or store the oil supply. Mounting lugs are usually provided on the crankcase structure for attaching the engine to the airplane. The portion of the induction system which distributes the mixture of air and fuel to the various cylinders is usually incorporated in one of the crankcase sections. This is called the **DIFFUSER** chamber. Accessory drives are provided in some portion of the crankcase leading to suitable mounting pads to which the necessary accessories may be attached.

Fig. 12. Allison Engine Crankcase.

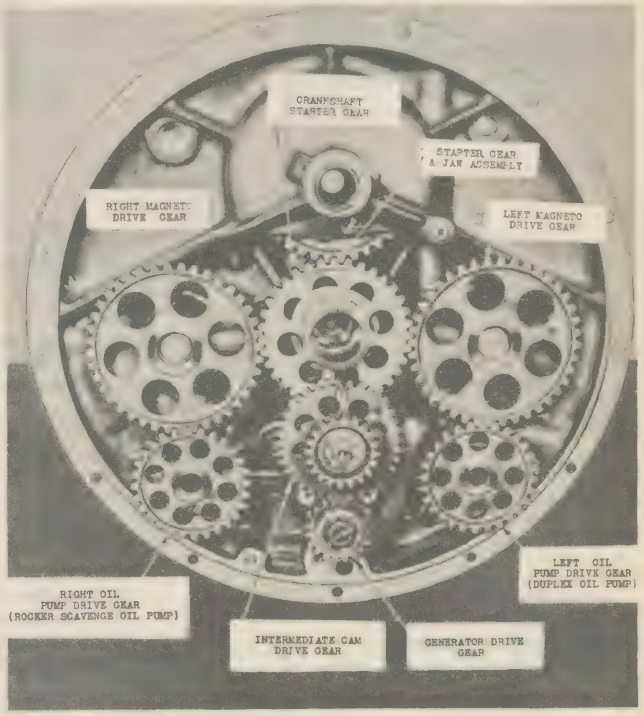

CRANKSHAFT STARTER GEAR
STARTER GEAR & JAW ASSEMBLY
RIGHT MAGNETO DRIVE GEAR
LEFT MAGNETO DRIVE GEAR
RIGHT OIL PUMP DRIVE GEAR (ROCKER SCAVENGE OIL PUMP)
INTERMEDIATE CAM DRIVE GEAR
GENERATOR DRIVE GEAR
LEFT OIL PUMP DRIVE GEAR (DUPLEX OIL PUMP)

Fig. 13. Accessory Drive Mechanism of Radial Engine.

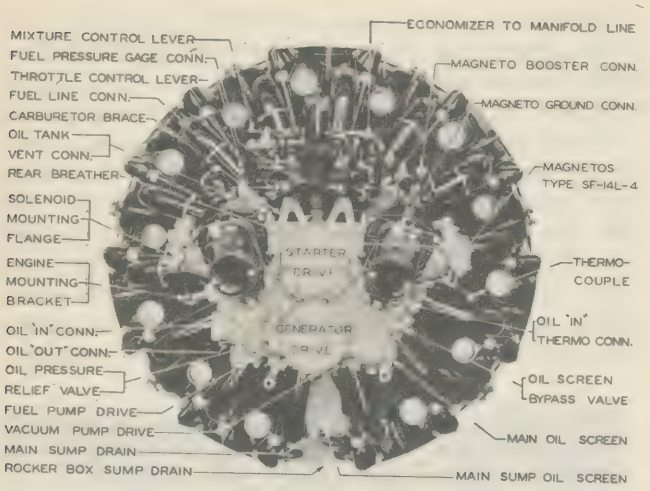
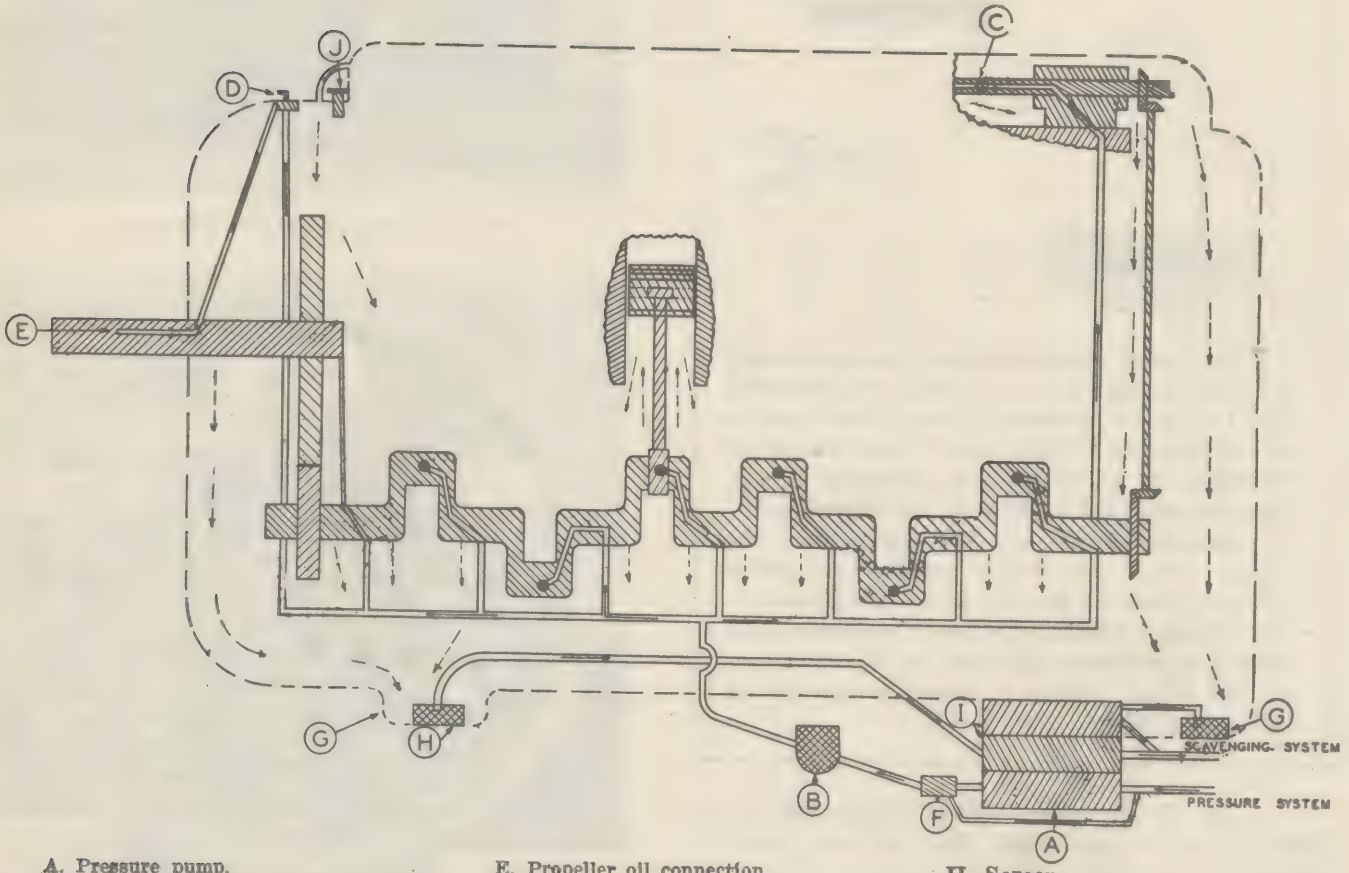


Fig. 14.

f. Lubrication System.--As stated before, the crankshaft is usually hollow in order to distribute oil under pressure to the main bearings (if of the friction type), connecting rod bearings, and accessory drives. Oil pressure is produced by a gear type PUMP driven by a gear on the rear shank. The variation in pump speeds due to the changes in engine speed from idling to full power is compensated for by a pressure relief valve, which maintains a constant pressure. Usually only those parts surrounding the crankshaft requiring it are supplied with oil under pressure. Such units as pistons, cylinders, rings, gears, anti-friction ball or roller bearings are oiled either by oil which splashes off the parts which are lubricated under pressure or by oil vapors which circulate in the crankcase.



A. Pressure pump.
B. Strainer
C. Hollow camshaft.
D. Propeller control valve.
E. Propeller oil connection.
F. Pressure relief valve.
G. Front sump.
G'. Rear sump.
H. Screen
I. Scavenging pumps.
J. Breather.

Fig. 15. Typical In-line or V-type Engine Lubricating System.

The oil supply in some engines is carried in the lower part of the crankcase. In radial engines it is usually carried in an external tank. In some high-powered engines it is necessary to cool the oil before it is pumped back to the storage tank and to incorporate some means of controlling oil fluidity.

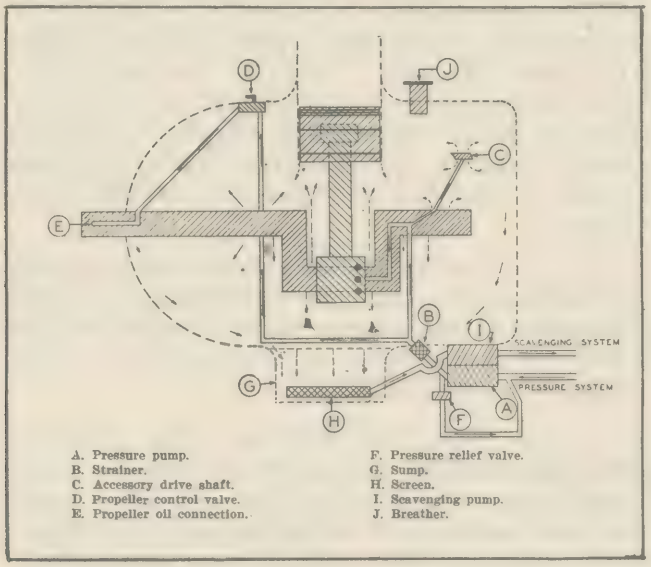


Fig. 16. Typical Radial Engine Lubricating System.

g. Cooling System.-- (1) Due to the large volume of waste heat to be dissipated around the cylinders and other parts, some means must be provided to control temperatures adequately and to hold them within safe limits under operating conditions.

(2) Cooling systems are divided into two general classes depending on the cooling medium, liquid cooling systems and air cooling systems.

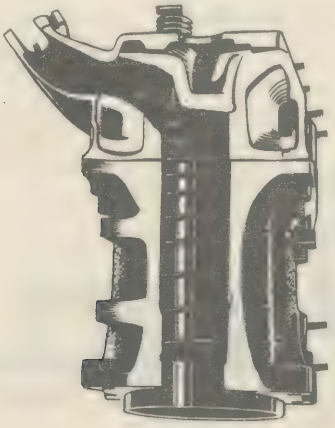


Fig. 17. Liquid Cooled Cylinder Jacket.

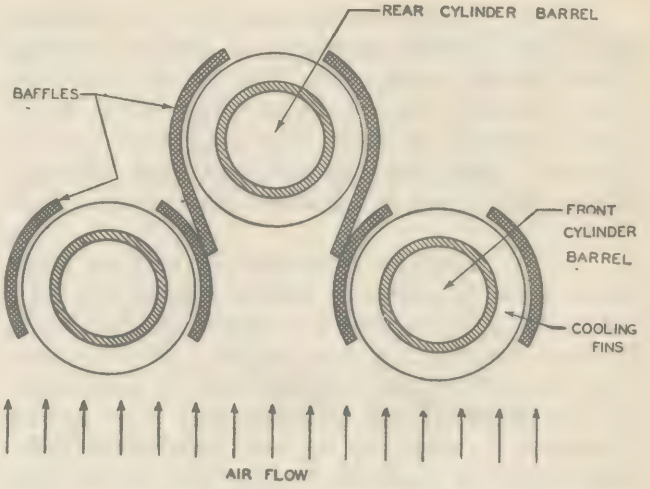


Fig. 18. Typical Pressure Baffles for a Twin Row Engine.

(3) The **LIQUID COOLING SYSTEM** consists of a jacket surrounding each cylinder, with inlet and outlet connections. Water, Prestone, or some other coolant is circulated through the jacket around the cylinder and then through an out manifold to the radiator core which is exposed to the radiator core which in turn is exposed to the air stream. Coolant is circulated through pipes commonly called **PLUMBING**. These are joined by suitable flexible connections.

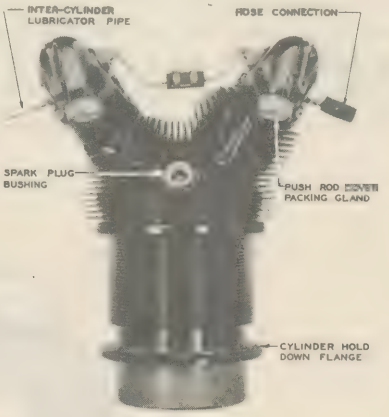


Fig. 19. Air Cooled Cylinder.

(4) In the **AIR COOLING SYSTEM** the cylinders are equipped with a proper arrangement of fin surface made integral with the cylinder barrel and head. A suitable baffle and cowl arrangement is provided to force the air stream into close contact with the fin surfaces. The flow of the air stream past the fins cools the cylinder. This flow will vary with the speed at which the aircraft is flown.

h. Induction System. -(1) A simple **INDUCTION SYSTEM** consists of a pipe leading from the carburetor to the intake port on the cylinder head. This pipe acts as a vaporization chamber for the fuel which has been atomized and sprayed into the air stream as it passes through the carburetor.

(2) The carburetor in its simplist form is a device which sprays the fuel into the air stream in approximately the correct proportion by weight. This is accomplished by the difference in pressure on the **FUEL FLOAT CHAMBER** and the lower pressure at the tip of the **DISCHARGE NOZZLE** which is located in the restricted or throat portion of the **VENTURI.**

(3) A **THROTTLE VALVE** is usually located in the carburetor barrel above the venturi. It controls the flow of air passing from the venturi into the cylinder. The higher the velocity in the venturi, the lower the pressure at the tip of the discharge nozzle, and since the pressure on the fuel in the carburetor chamber is nearly atmospheric, the amount of air flow through the venturi controls the fuel flow from the main jet into the air stream.

(4) The throttle valve, if in the closed position during a glide, will cause a suction in the intake system which acts as a **BRAKE** on the piston within the cylinder, and thus as a brake on the entire engine. This suction may be realized by observing the action of the vacuum motor which drives the windshield wiper on an automobile. When the throttle is closed, a small amount of air and fuel is taken into the cylinder and the engine runs slowly (idles). Since the suction condition in the intake manifold is great under these conditions, the wiper operates rapidly. When the throttle is opened suddenly, the air outside of the carburetor, which is at atmospheric pressure, rushes into the intake pipe and cylinder to fill the suction. This furnishes a large amount of fuel air mixture which causes the engine to accellerate rapidly, and the wiper then operates slowly if at all because of insufficient vacuum.

(5) The accessories required by carburetors to increase performance, allow operation at altitudes, and meet demands for great economy will be discussed in the chapter on carburetion.

i. Ignition System.--The present **IGNITION SYSTEM** consists of one or more spark plugs located in the cylinder head and some means of furnishing an itensified high voltage, electrical current. This will jump the spark plug gap under the high pressures which obtain within the combustion chamber when the throttle valve is wide open. The ignition units are driven by the engine and timed in such a manner as to produce a spark in proper relation to piston and crankshaft position during the compression stroke.

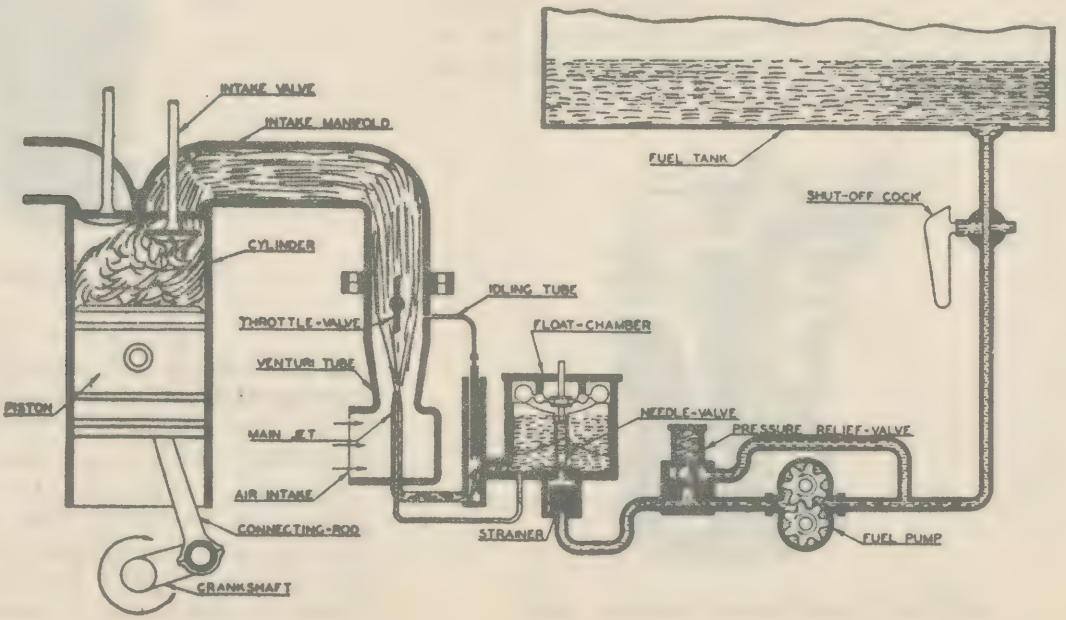


Fig. 20. Typical Fuel System.

3. **ELEMENTARY PRINCIPLES OF GASOLINE ENGINES.**--All gasoline engines, regardless of the number of cylinders, have the same principle of operation. Fig. 21 shows a cross-section of a conventional type of automobile engine. This is shown for the purpose of identifying the various parts of the engine and to assist in the understanding of functions of the various parts.

a. Operating Principles of a Gasoline Engine.--(1) A gasoline engine is called an internal combustion engine because the burning of the fuel takes place inside the engine cylinder, between the cylinder head and the piston, or in the combustion chamber, as it is more commonly called. This type of engine is able to use for fuel either natural gas, gasoline, kerosene, or alcohol. This book discusses the type of engine specifically designed to use gasoline as a fuel.

(2) When a compressed mixture of air and gasoline vapor is ignited, it burns with great rapidity and produces intense heat which causes the gases to expand and thus develop pressure against the head of the piston, forcing the piston down and rotating the crankshaft by means of the connecting rod. This combustion is so rapid that it is often referred to as an "explosion," but the use of this term is incorrect. The intensity of the pressure of the gas decreases as the piston is forced downward on the power stroke, due to the fact that the gases are permitted to expand and occupy a larger space. After the mixture is ignited, combustion begins. There is a small interval of time until the maximum pressure is reached. For this reason the spark is usually timed to occur just before the piston reaches the top of the cylinder so that maximum pressure will be exerted on the piston as it starts on its downward movement. The pressure causes the piston to slide the length of the cylinder from the cylinder head toward the open end.

(3) The piston is connected to the crankshaft *throw* (similar to a crank) by a *connecting rod, fig. 22.*

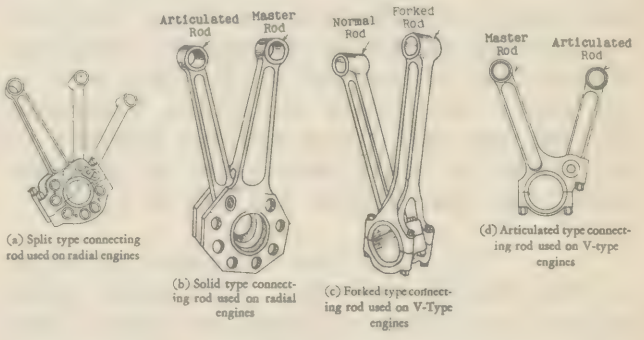
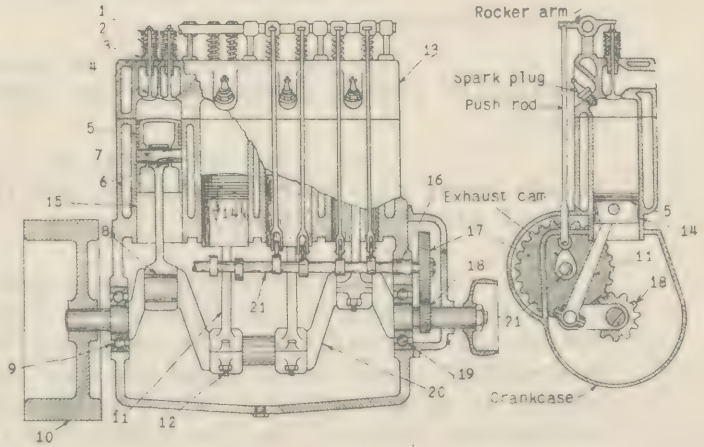

Articulated Rod
Master Rod
Normal Rod
Forked Rod
Master Rod
Articulated Rod
(a) Split type connecting rod used on radial engines
(b) Solid type connecting rod used on radial engines
(c) Forked type connecting rod used on V-Type engines
(d) Articulated type connecting rod used on V-type engines

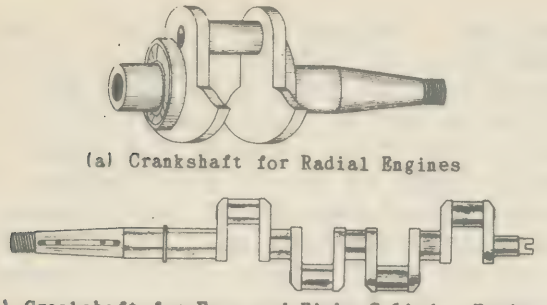
Fig. 22. Types of Connecting Rods.

(4) The back and forth motion of the piston in the cylinder is called *reciprocating motion*. Reciprocating motion of the piston is changed to a *rotary motion* by means of a *crankshaft, fig. 23.*



(1) VALVE-SPRING SEAT
(2) VALVE SPRING
(3) VALVE GUIDE
(4) VALVE
(5) PISTON RING
(6) PISTON-PIN BUSHING
(7) PISTON PIN
(8) CONNECTING ROD BEARING
(9) CRANKSHAFT BALL-BEARING-REAR
(10) FLY WHEEL
(11) CONNECTING ROD
(12) CONNECTING-ROD BOLT
(13) CYLINDER HEAD
(14) PISTON
(15) CYLINDER
(16) CAMSHAFT FRONT BEARING
(17) CAMSHAFT GEAR
(18) CRANKSHAFT PINION GEAR
(19) CRANKSHAFT BALL BEARING FRONT
(20) CRANKSHAFT
(21) CAMSHAFT

Fig. 21. A Four-Cylinder Automotive Gasoline Engine with Valves-in-the-Head Operated by Push Rods and Overhead Rocker Arms.



(a) Crankshaft for Radial Engines

(b) Crankshaft for Four and Eight-Cylinder Engines

Fig. 23. Types of Crankshafts.

(5) One complete turn of the crankshaft in which the piston moves from one end of the cylinder to the other end and back again, is called a ***revolution***. One-half of a revolution of the crankshaft moves the piston from either end of the cylinder to the other end, which is called a ***stroke***. Thus we see that there are two strokes of the piston to every revolution of a crankshaft; one down stroke and one up stroke.

(6) There are two types of valves in each engine cylinder. The ***inlet*** valve admits the mixture of gasoline and air from the carburetor to the cylinder. The ***exhaust*** valve permits the burned gases to escape to the outside air after combustion. These valves may be on the side of the engine or overhead. They can be operated by push rods when on the side, or when overhead by combination of push rods and rocker arms, or by an overhead camshaft.

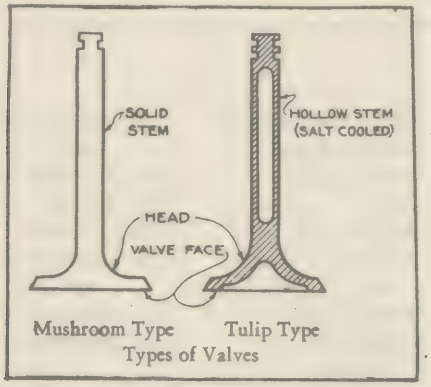


Fig. 24. Types of Valves.

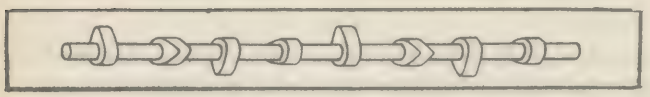


Fig. 25. Camshaft for 4-Cylinder Engine.

(7) The valves shown in fig. 21 are of the overhead type and are operated by push rods and rocker arms. This principle is used to a great extent on the air-cooled, radial type aviation engines, and the overhead camshaft is used to a large extent on the water-cooled aviation engines when there are a number of cylinders in line.

(8) The ignition on automobile engines is usually of the generator-battery high tension coil system, while on aviation engines the high tension magneto is used almost exclusively, each engine having a dual ignition system with two magnetos, each operating a spark plug in each of the cylinders. Each cylinder, therefore, has two spark plugs, each plug being operated by a different magneto.

b. The Four-Stroke Cycle Principle.--(1) In order to operate continuously and deliver power, each cylinder of the engine must go through a routine of operation, each series of events being performed over and over again in the same order. Each individual operation is known as an event and a complete series of events is known as a cycle or as a cycle of events.

(2) In a gas engine, the following events must take place in each cylinder:

(a) Cylinder filled with explosive mixture.

(b) The mixture must be compressed.

(c) Ignition or setting fire to the mixture.

(d) The burning of the gases forcing the piston downward on the power stroke.

(e) The forcing of the burned gases out of the cylinder on the exhaust stroke.

(3) The four-stroke cycle principle is used almost exclusively on automotive and aircraft gasoline engines. The four-stroke cycle is so named because each piston in every cylinder must make four strokes to complete the five events of the engine cycle. Since four strokes require two revolutions of the crankshaft, we see that there is but one cycle of events completed for every two revolutions of the

crankshaft. This means also that there will be but one power stroke for every two revolutions of the crankshaft.

(4) Internal combustion engine mechanics is based on taking the fuel into a cylinder, compressing this fuel, setting the power free by ignition so that the expansion sets free energy to be transmitted to the fan or propeller by means of a mechanical linkage to an eccentric that will change the lineal motion into rotating motion.

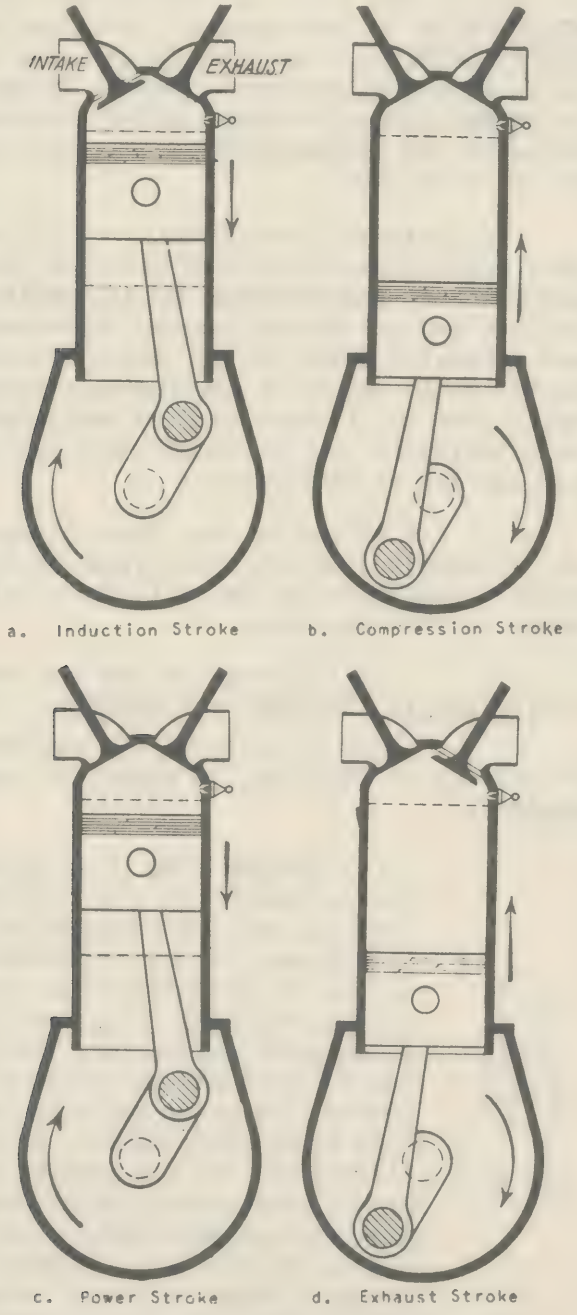


Fig. 26. The Otto 4-Cycle Principle.

(a) The **FIRST** or **INDUCTION STROKE** *(fig. 26-a)* is the downward travel of the Piston which creates a vacuum in the cylinder that draws a mixture of gasoline and air prepared by the **CARBURETOR** into the cylinder thru the open **INLET VALVE.**

(b) The **SECOND** or **COMPRESSION STROKE** on the **INLET VALVE** is closed and the upward travel of the Piston compresses these gases in the cylinder head or **COMBUSTION CHAMBER** producing a high-powered charge on the top of the Piston *(fig. 26-b).*

(c) The **THIRD** or **POWER STROKE** is produced by igniting the charge in the compression chamber by a high tension spark furnished by the magneto and delivered to the cylinder by the spark plug. The burning of the compressed gas drives the Piston downward rotating the crankshaft *(fig. 26-c).*

(d) The **FOURTH** or **EXHAUST STROKE** is the upward travel of the Piston, which drives the burned gases out through the open **EXHAUST VALVE** thus clearing the cylinder for the next charge *(fig. 26-d).*

c. *Valve Timing.*--(1) Valves must be timed in order that the gas may enter the cylinders at the proper time and when the piston is at the proper position. The regulating of the valves is called timing. In the timing of an internal combustion engine, there is one thing that supersedes all others, due to its effect on the power output. That is the position of the closing of the exhaust valve. Of the four valve timing positions, the exhaust valve closing can be varied the least without causing a loss of power. This being the case, if we are entirely unfamiliar with any particular make of engine, we can nevertheless time it to a fair degree of accuracy if we understand the underlying fundamentals of valve timing.

(2) Practically all exhaust valves close at 10° after top dead center or within two or three degrees of that position. There are other factors which enter into the case, such as valve lift, clear diameter, and crankshaft speed, but as aviation engines are designed for a maximum power output per pound of weight, this practice will hold good. This considers only engines wherein the intake and exhaust cams are on one shaft or bank.

Where a separate intake camshaft is used, the intake valve timing is set according to the valve's opening position which should occur immediately after the exhaust valve closes, without any degree of variation.

(3) Valve timing methods as applied to airplane engines differ from those used on automobiles because of the lack of a flywheel on the former, but in both cases the valve opening and closing positions bear a certain fixed relation to dead center position of the piston.

(4) Valve timing is a relatively simple operation, but requires a knowledge of procedure, as well as timing position in degrees.

(5) A timing disc with degrees marked thereon is generally used on "V" engines, while the cylinders on the radial and rotary engines, being equally spaced, provide a very good substitute.

(6) Factory specifications for valve tappet clearances (the clearance is the distance between the end of the valve and the tapped adjusting screw) should be known in order to adjust and time the valves properly.

(7) With a timing disc and known valve timing, clearances can be determined. Automobile valve clearances vary from .003 of an inch to .007 or .008, while one airplane engine of 150 hp. may use .078 and the same make of 220 hp. engine use .118. Obviously, knowledge of such dimensions is a necessity. All valve adjustments must be securely locked by whatever method the manufacturer provides. The intake valve opens at approximately 10° before top dead center on the exhaust stroke and closes about 40° past bottom dead center on the compression stroke. The exhaust valve opens approximately 45° before bottom dead center on the power stroke and closes at about 10° after top dead center on the intake stroke. The degrees of opening and closing of the valves vary with the different makes of engines. In setting the valve, use factory specifications.

d. Valve Overlap.--(1) The **EXHAUST VALVE** starts to open before **BOTTOM CENTER** on the **POWER** stroke. It is allowed to remain open a little past top center on the intake stroke. This **LEAD** and **LAG** in the exhaust valve operation takes care of the **INERTIA** of gases and gives a thorough cylinder cleaning.

(2) The **INTAKE VALVE** is late or **LAGS** at the end of the **INTAKE** stroke. The **INTAKE VALVE** opens slightly before **TOP CENTER** causing a vacuum which speeds up the rush of gas into the cylinders. The **INTAKE VALVE** is left open slightly after **BOTTOM CENTER** to allow the inward rush to continue and give maximum volume of intake. The **INTAKE VALVE** is closed before the reaction of the **COMPRESSION** stroke reaches the cylinder head.

e. Cylinder Arrangement.--(1) Aircraft engines may be divided into two general classes, **LIQUID-COOLED** and **AIR-COOLED.** Although the air-cooled engines have been more generally used in the past, modern liquid-cooled engine is increasing in popularity due to its excellent streamlining characteristics and the ease with which its head may be dissipated.

(2) Either of the above classes may be further divided into types, based on the arrangement of the cylinders with respect to the crankcase.

(a) Air-cooled engines are usually **RADIAL, IN-LINE,** and **OPPOSED.**

(b) Liquid-cooled engines are usually **V, IN-LINE, OPPOSED, X,** and **DOUBLE V.**

Fig. 27.

(3) **IN-LINE TYPE** (fig. 27)--The cylinders of the in-line type engines are arranged in a single row on the crankcase, either in an upright or inverted position. This type is an entirely satisfactory design for low-performance airplanes; however, it is not suitable for high horsepower output. Practically all of the modern in-line engines are of the inverted type. The maximum number of cylinders in this type engine is usually limited to six, to facilitate cooling and avoid prohibited weight per horsepower.

Fig. 28. V-Type.

(4) **V-Type** *(fig. 28)*--The cylinders of V-type engines are arranged on the crankcase in two rows or banks forming a V. The two banks of cylinders are directly opposite each other, which permits two sets of connecting rods to operate on the same crankpin. This arrangement greatly reduces the weight per horsepower as compared to the in-line type, with very little sacrifice in the head resistance of the aircraft.

(5) **Double V or Fan-Type** *(fig. 29)*--In an attempt to raise the limit of available horsepower per unit of weight, a double V-type, liquid-cooled engine has been developed. It consists of four banks of cylinders arranged in a fan shape. The chief advantage in such an engine is that it gives practically the same horsepower as two single V-type engines without materially increasing the frontal area required for a single V-type engine. The two crankshafts are employed to drive the propeller.

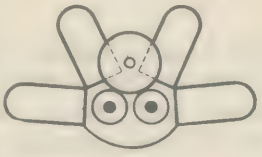


Fig. 29. Double V or Fan Type.

Fig. 30. X-Type.

(6) **X-Type** *(fig. 30)*--In this type engine two of the four banks of cylinders are arranged on one side of the center line of the engine while the other two are equally spaced on the opposite side in the form of the letter X. This arrangement permits the use of only one crankshaft in contrast to the two crankshafts in the double V-type.

Fig. 31. Opposed or Flat Type.

(7) **Opposed or Flat Type** *(fig. 31)*--In the opposed type engines the cylinder banks are arranged horizontally, in two rows, on opposite sides of the crankcase. A single crankshaft of conventional design is employed and the engine may be constructed with an even number of cylinders. Due to the flat shape of the engine, it is particularly adaptable for streamlining and makes possible wing engine installations.

(8) **Radial Type** *(fig. 32)* In single-row radial type engines the cylinders extend radially from the center line of the crankshaft in any odd numbers, usually between 3 and 9. The cylinders are evenly arranged in the same circular plane. A single throw 360° crankshaft is used, to which all of the connecting rods are attached resulting in a minimum number of working parts as well as a considerable savings in weight.

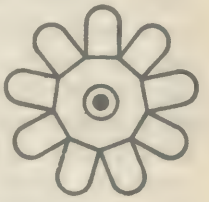


Fig. 32. Single Row Radial Type.

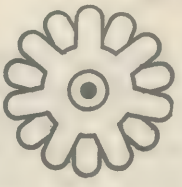


Fig. 33. Double Row Radial Type.

(9) The **Double-Row** radial engine *(fig. 33)* resembles two single-row engines combined on a single crankshaft. The conventional number of cylinders used is either 14 or 18, which in effect would be either two 7-cylinder engines or two 9-cylinder engines. A two-throw, 180° crankshaft is used to permit the cylinders of each row to be alternately staggered on the common crankcase. The alternate staggering allows the cylinders in both the front and rear rows to receive sufficient air from the slip stream for the proper cooling.

4. COOLING.

a. Reasons for a Cooling System.

(1) Excessive heating in any internal combustion engine is undesirable because it impairs the lubrication, affects the behavior of the combustion of the fuel charge, and weakens the strength and durability of engine parts. High heat will "crack" lubrication oil, reducing its viscosity and destroy its lubricating qualities. Also if the temperature inside the cylinder is too high, the fuel mixture

will be preheated and spontaneous combustion will take place before the proper time for the mixture to be ignited. This will cause knocking, detonation, and all the ills that follow. The strength of many of the engine parts depends on their heat treatment; therefore, high temperatures reduce very materially the strength of these engine parts. High temperatures will cause the parts to become warped, elongated, and will cause excessive expansion which in some cases may force the moving parts together with tremendous pressure causing them to freeze or lock together, therefore stopping the motor.

(2) To prevent the above difficulties occuring, some means must be used for cooling the engine so that it will operate at the most efficient temperature. The means employed in all engines is called the cooling system.

b. Liquid-Cooling System.

(1) There are three general types of liquid-cooling systems employed on internal combustion engines: The thermosyphon, the water vapor or steam, and the forced circulation systems. Only the last type of system will be described, since it is the one employed on all modern liquid cooled airplane engines. See fig. 34.

(2) The forced circulation liquid-cooling system consists of the following essential parts:

(a) A radiator
(b) A circulation pump
(c) Water jackets on the engine cylinder
(d) Necessary piping and connections.

(3) With the engine running we will trace the operation of this system. Starting with the liquid at the radiator outlet (at bottom of radiator), it is drawn through a pipe into a pump, generally of the centrifugal type. The pump impellers force the liquid out through connections into the water jackets around the cylinders. The liquid circulates around the outside of the cylinder walls, absorbs heat from them, and is discharged from the water jacket outlet or outlets into a pipe which carries it to the radiator inlet. As

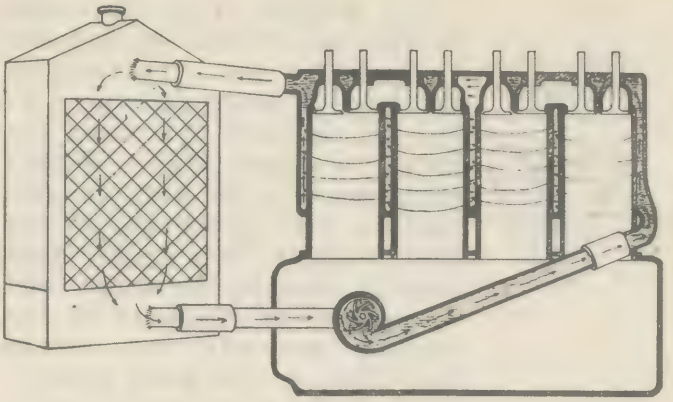


Fig. 34. Liquid Cooling System (Forced Circulation Type).

the liquid passes down through the radiator, it transfers heat to the walls of the cores and tubes, which in turn transfer it to the passing air. The liquid has now been cooled and is ready to leave the radiator outlet again.

(4) *Radiators.*--Three types of airplane radiators in use at present are the core, plate, and wing radiators. The core type, fig. 35, is built in two forms,

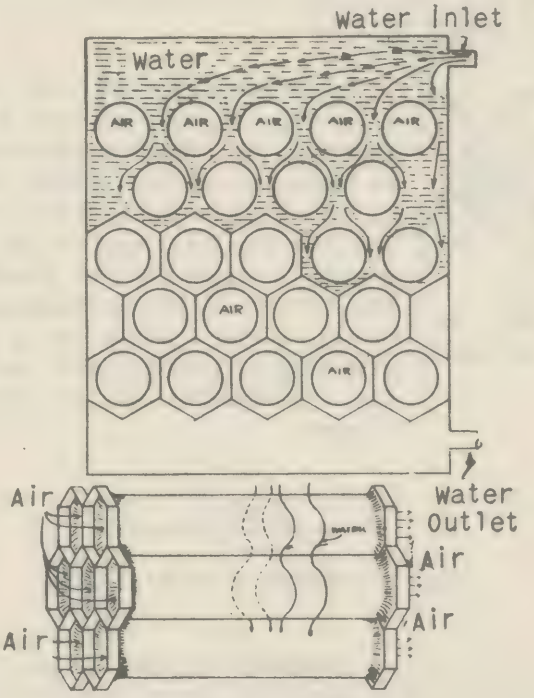


Fig. 35. Core Type Radiator Construction.

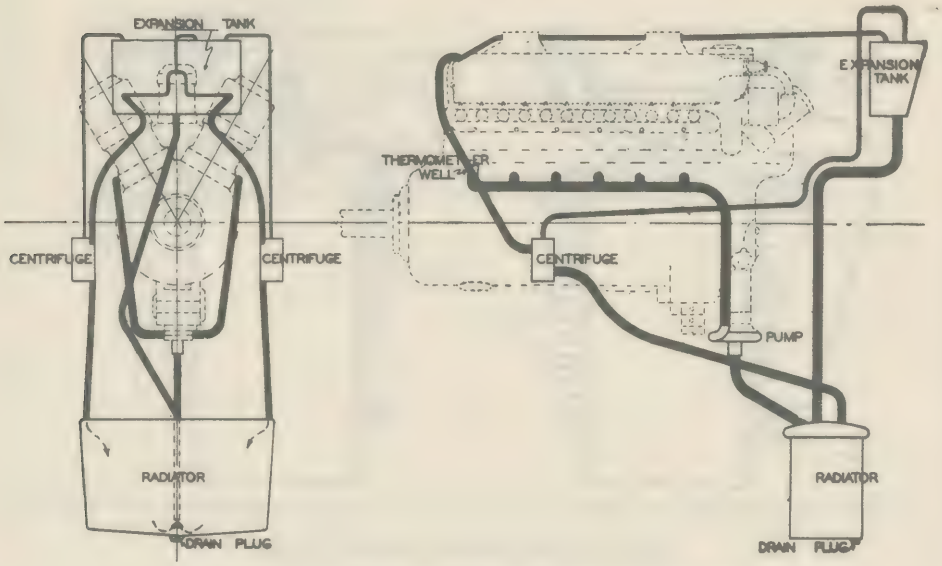


Fig. 36. Typical Liquid Cooling System

the nose type and tunnel type. The nose type is generally located ahead of the engine and has a comparatively large frontal area and small depth. The tunnel type is generally located below the engine, and is constructed with smaller frontal area and greater depth. The core type of radiator is employed for cooling on most modern airplanes mounting liquid-cooled engines. The plate type is little used in the United States although used to some degree in France. The wing type radiator was first developed by Curtiss for use on racing airplanes. Its disadvantages caused its use to be abandoned. It consists essentially of a thin metallic shell, so built as to form a portion of the wing surface, the trailing edge and the entering edge forming the inlet and outlet headers. Liquid circulates through the thin shell from front to rear, and is cooled by the passing air.

(5) There are two liquids, water and ethylene glycol (Prestone), which may be used as coolants for liquid-cooled aircraft engines. Water is universally used because of its availability and high specific heat. The disadvantages in its use compared to Prestone are:

(a) Its high rate of evaporation or low boiling point necessitating a large radiator in the cooling system. Prestone, with a high boiling point, permits the use of a smaller radiator reducing heat resistance and weight per horsepower.

(b) Water has a high freezing point (30° F.), while Prestone has a low freezing point (0° F.).

(c) Water used as a coolant comes from wells, rivers, and lakes; even though filtered, it is somewhat impure. Prestone is considered pure when first placed in the cooling system. Its natural tendency to loosen rust from certain parts requires frequent draining and thorough straining before it is returned to the system.

c. *Air-Cooling Systems.*

(1) The excess heat developed in the cylinder of the air-cooled airplane engine is cared for by having its cylinders and valve ports so constructed and arranged that there will be a uniform flow of air about them during engine operation. Modern air-cooled airplane engine cylinders are generally constructed of aluminum alloy with concentric or lateral fins integrally cast and machined. A steel liner is screwed and shrunk into these cylinders, and the valve seats and bushings, generally of bronze, are shrunk or pressed and expanded into place in the head. Air-cooled engines' cylinders have been a problem since the advent of the first air-cooled engine, and in recent years considerable experiment and research has resulted in development of dependable and satisfactory cylinders. *Fig. 37* is a sketch of a modern air-cooled airplane cylinder.

(2) Air-cooled engines as a rule are lighter than water-cooled engines. Because they operate at higher temperatures than water-cooled engines, a lower compression pressure (not more than 75lbs. per sq. in.) is necessary to prevent preignition. There is also a limit to the bore of the cylinder, 5 in. being the highest practical value. In the past the air-cooled engines suffered from over-heating, burned and broken exhaust values, and high fuel

consumption. The exhaust valves of the air-cooled engines of today are just as reliable as those of the best water-cooled engines. With the modern air-cooled cylinder, cooling is a minor trouble, the great disadvantage lying in need of development. Most valve mechanisms are air-cooled, are exposed to the air and dust, and are poorly lubricated, but this trouble is being rapidly overcome by the engine manufacturers.

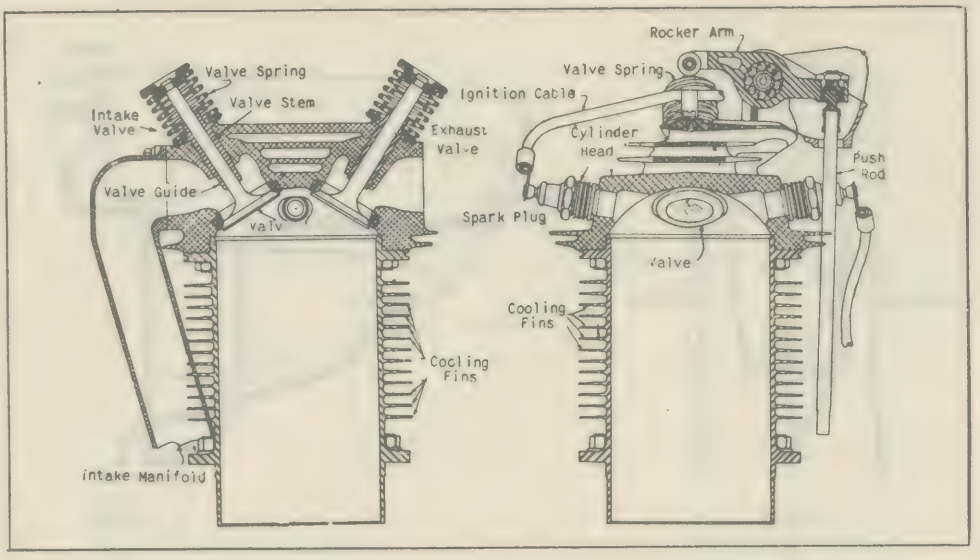


Fig. 37. Air-Cooled Engine Cylinder.

d. Temperature Control.

(1) Variations in atmospheric temperature and engine performance result in variations of heat radiation from airplane engine cooling systems, and since engines operate most efficiently at a certain constant temperature, some form of engine temperature control is necessary. There are three general methods of temperature control employed on water-cooled engines.

(a) Radiator shutters
(b) Engine or radiator
(c) Variable flow

(2) The shutter type of control should be familiar to everyone. Shutters similar in principle to those used on dwelling house windows are placed in front of the radiator and control the flow of air through the radiator. This variation in air flow causes a variation in heat radiation, and therefore a variation in engine temperature. The use of the radiator shutter is the method most generally used for airplane engine temperature control. The by-pass control provides a water flow by-pass past either the engine, the radiator, or sections of the radiator. In the engine by-pass system, a manually or automatically operated valve allows part of the cooling water to flow from the pump directly to the radiator inlet, thus varying the volume of flow through the engine only. The radiator by-pass system has a manually or automatically operated valve which allows part of the water to flow through the radiator, and part through a connection between the radiator inlet and outlet, all of the cooling water flowing through the engine. This system varies the volume of water flowing through the radiator only. Some variations of this system provide for selective by-passing of certain sections of the radiator. This system was used with the wing type radiator.

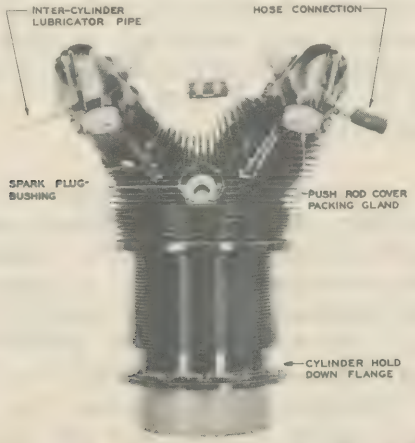


Fig. 38. Late Type Air-Cooled Cylinder.

(3) Due to the high temperature at which air-cooled engines normally operate, little effort has been made to provide a temperature control for this type of power plant. Should variable temperature control become necessary for this type of airplane engine, it will not be a difficult problem to design a shutter system for varying the flow of air past the cylinders.

5. **Ignition.**

a. Definition.--By ignition we mean the act of igniting or setting fire to the mixture in the engine cylinder at the proper instant. For this purpose the electric spark is used, the heat of the spark serving to start the combustion.

b. Importance of Proper Ignition.

(1) After the mixture charge has been taken into the cylinder and compressed, the next step in the cycle is to set it on fire or ignite it. Ignition of the mixture is of the greatest importance, for if not done correctly, the engine will lose power. Each charge of mixture will produce a definite quantity of heat when it is burned, this heat in turn being capable of producing a definite amount of pressure and power. If the engine is to run efficiently and develop full power, the greatest possible portion of this pressure should be utilized in driving the piston downward on the power stroke. The burning of the mixture in a cylinder is not, as is popularly supposed, an explosion, but instead it is a very rapid combustion. It is relatively slow, however, when compared with the speed of piston travel.

(2) As the maximum power is obtained from a motor by having the gases reach their greatest pressure as the piston starts its downward travel, we must start the gas burning before this point is reached. This point of starting is determined to a great degree by the motor speed; hence the need for having the spark occur before the piston reaches top dead center on the compression stroke. This is called spark advance.

(3) A spark plug is simply an insulator which causes the spark to occur inside the cylinder, instead of outside.

(4) There is an aid to rapid combustion, without which we would never be able to obtain the high speeds possible with some engines. This is what is called turbulence, a rapid swirling movement of the gases during compression, caused by the shape of the combustion chamber and intake passage. It is a matter of design entirely.

(5) When cranking an engine by means of the propeller, if it is equipped with a battery system, the first thing to do is retard the spark. This will prevent the engine from kicking backward. A back kick has often resulted in serious injury. The proper method of cranking with the propeller will be clearly demonstrated and practiced at the flying field. Safe cranking from the ground requires practice.

c. Ignition Systems.--There are two main types of ignition systems, the low tension system and the high tension jump spark system. The low tension system, although having been used somewhat in the past, has now been entirely abandoned. The jump spark ignition system is the only one used at the present time due to its flexibility regarding the timing of the spark. This system is in universal use on high speed engines. The jump spark system is divided into two classes, the high tension battery-generator system and the high tension magneto system.

(1) **High Tension Generator Battery Ignition Systems.** (a) *Essential Elements.*--The essential elements of any electric ignition system are:

1. A simple and practical source of low voltage primary current.

2. An electrical transformer to change the low voltage current to a very high voltage.

3. A breaker, mechanically operated, to interrupt the primary current at the proper instant, permitting the transformer to function.

4. A condenser to absorb the self-induction voltage of the primary and prevent arcing at the breaker points.

5. A distributor to feed the high voltage current to the proper spark plugs.

6. A safety gap to protect the secondary winding and prevent it from burning out.

(b) **The Generator.**--*1.* In this system the current is supplied by the generator and is stored in the storage battery.

2. The generator is usually small, light and rugged, and is

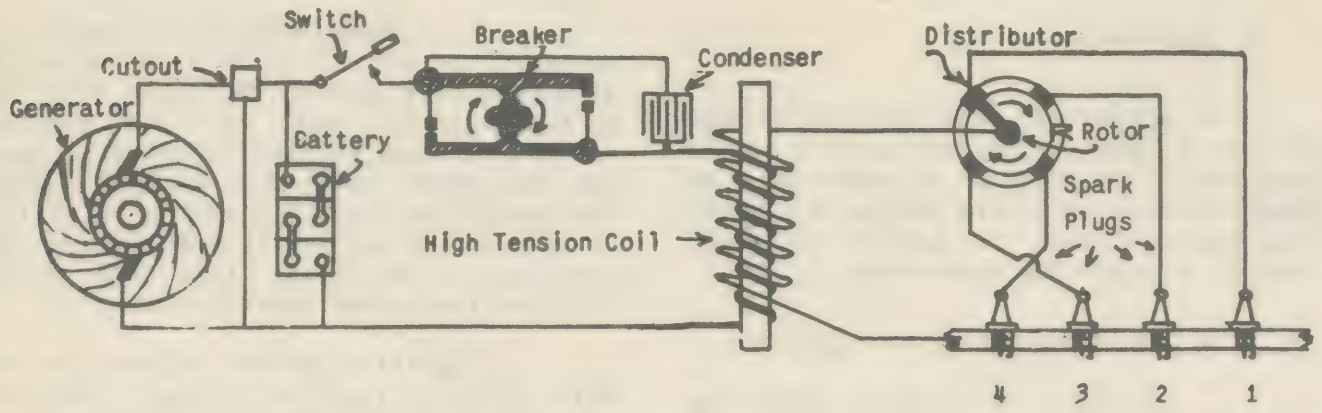


Fig. 39. Circuit Diagram--Battery-Generator Ignition System.

driven directly from the gear train of the engine. In order that voltage and current may be maintained at approximately constant values for varying engine speeds, a voltage regulator is usually incorporated in the system.

3. When the speed of the engine falls below that necessary to generate current of value sufficient to charge the battery, the battery will discharge back through the generator unless some provision is made for disconnecting the generator when this occurs. An automatic electrical device, called a "generator cut-out," automatically cuts the generator-battery circuit when the current falls below the desired value.

(c) **The Battery.**--*1.* The battery stores up electrical energy in the form of chemical energy but returns this electrical energy when the battery is connected to an external circuit. The desired voltage is obtained by connecting a sufficient number of cells in series, forming the storage battery.

2. The battery is usually of the lead-cell type having four or six cells of varying ampere-hour capacity. A provision is usually made in airplane batteries for preventing spilling of electrolyte when the battery is on its side or inverted.

3. The cells are given a deep section, the plates occupying only the lower half of the cells. The electrolyte level should be from one fourth to one half inch above the top of the plates. Due to a baffle placed above the plates, it is impossible to see the electrolyte through the vent plug bushing, so a long nose hydrometer is necessary for testing this type of battery.

(d) **The Transformer.**--The transformer or induction coil is of the conventional type, consisting of a primary and secondary wound about a common core and properly insulated. In some cases it is integral with the distributor head, and in others it is mounted on the airplane, separate from the engine.

(e) **The Breaker Mechanism.** The breaker mechanism usually consists of two low tension interrupters connected in parallel and operated in synchronism by a cam. On some engines the breaker cam is driven off the generator armature shaft, and in others it is driven by some portion of the gear train such as the camshaft gear. The breaker assembly may or may not have attached to it the distributor assembly. Figure 39 shows the movable and the stationary contacts used to make and break the battery (low voltage) current, which is carried from the induction coil to the station contact by the heavy wire. The moving contact, which is really a short lever, is held in its normal position against the stationary contact by a flat spring. At the side of the contacts there is a small cam which has as many lobes, or teeth, as there are engine cylinders. This cam revolves at half the engine speed and when one of its lobes is opposite the moving contact, the lobe pushes this contact so as to separate slightly the contacts, or breaker points, and thus interrupts the battery current through the ignition coil. Every time the contacts or breaker points

separate, there is a high voltage current induced in the secondary of the induction coil. The rotation of the cam and the distributing arm must be so timed that this induced current will make the ignition spark in each cylinder at just the right instant.

(f) *Condenser.*--A condenser consists of a number of sheets of tinfoil separated from each other by sheets of oiled paper. Every alternate tinfoil sheet is connected to one side of the breaker points circuit and the ends of the other tinfoil sheets are connected to the other side of the break circuit. If a condenser is connected to an induction coil in this way and the battery current flowing in the coil is interrupted, the battery current, instead of sparking across the breaker points, spreads over the sheets of tinfoil and produces a charge of electricity which is stored to be given back to the circuit when the points again come together. By this quick and clean breaking of the low-voltage current, an induced current of higher voltage is obtained than would otherwise be the case.

(g) *The Distributor Assembly.*

1. The distributor may be considered as being composed of two parts: the rotor or brush and the high tension terminal ring or track.

2. The rotor, usually of some insulating material such as bakelite, is driven by the engine at one-half crankshaft speed in order to distribute the high tension current to the correct cylinders at the proper instants. It carries on its outer end either a brush or a metal electrode, and some provision is made for maintaining connection between the brush and the secondary of the induction coil.

3. The terminal ring, of some insulating material, has imbedded in it the desired number of metal terminals--one for each spark plug, spaced at the correct intervals. Its diameter is such that the rotor brush will make contact with each terminal in turn, or that there will be a slight clearance between the rotor electrode and each terminal. In this way a high tension current can easily jump the gap when the electrode is opposite the terminal.

4. Each terminal is connected to a spark plug through a length of heavily insulated wire.

(h) *Safety Gap.*--In case the main secondary lead to the distributor became accidentally broken, the secondary current would rise to a very high value, sufficient in most cases to burn out the secondary winding. In order to prevent this happening, a safety gap is usually built into the ignition device. In this connection the safety gap would serve to dissipate any excessive voltage.

(i) *Principle of Operation.*--Fig. 39 shows a typical circuit diagram for a battery ignition system. The operation is as follows: as the breaker cam is rotated by the engine, the breaker points are successively closed and opened. With the breaker points in the closed position, the battery current flows into the primary winding of the induction coil, building up the magnetism in the coil to its maximum value. Upon the opening of the breaker points the magnetizing influence is removed and the lines of magnetic force surrounding the core collapse, inducing a small voltage in the primary winding and a very high voltage in the secondary winding. The voltage in the primary winding is of no practical value and is absorbed by the condenser across the breaker points. The high voltage current generated in the secondary winding is fed by the distributor to the proper spark plug. The breaker and distributor mechanisms are so geared that the breaker points open and produce a spark every time the distributor rotor is opposite a segment leading to a spark plug. The timing of the spark is controlled by varying the position at which the breaker cam opens the breaker points.

(2) **High Tension Magneto.**--A high tension magneto differs from the battery ignition system only as to its source of primary current. The high tension magneto generates its own primary current. It may be described as a self-contained device for generating low voltage current, transforming this low voltage current to a high voltage and distributing it to the proper spark plugs at the correct instants.

(a) *Generating Primary Voltage.*--1. The generation of the voltage in the primary winding of a magneto depends upon the principle that if the number of lines of magnetic force passing through a coil is varied--that is, either increased or decreased--a voltage will be generated in the coil. The greater the rate of change of a number of lines of force through the coil, the greater will be the voltage. In the magneto shown in fig. 40 the flux (lines of magnetic force) of the permanent magnet passes from the north to the south pole through the field pieces and core, hence, through the primary winding. As the armature is revolved, the number of lines of force passing through the primary winding change as shown in (A), (B), (C), and (D) of fig. 40.

2. In (A) all of the flux passes through the core as indicated by the arrows. As the core moves a small distance from this position, the path of the flux through the core will not change and there will be no voltage generated. As position (B) is approached, the lines of force are distorted but will continue to pass through the core because the reluctance of the iron core is less than that of the air and the flux tends to take the easiest path. However, due to the fact that the flux is crowded into the upper left hand pole tip, the latter becomes saturated and some of the flux will leak from the lower left hand pole tip directly across to the right hand pole tip and this part of the flux will no longer pass through the core. Hence, the number of lines passing through the core and primary winding will be slightly decreased which will cause a small voltage to be generated in the primary winding.

3. At the instant the armature reaches position (C) all of the flux will pass directly across the ends of the core and, hence, none will pass through the center of the core and primary winding. Just before the armature reaches this position the flux is entering the core at the lower end, as shown in (B), and just after the armature passes the 90° position, the flux enters the core at the lower end, and leaves at the upper end, as shown in (D), hence as the armature passes through position (C), the flux through the core decreases to zero and then increases in the opposite direction; that is, it reverses. In this position (C), the flux changes at the maximum rate and, therefore, the maximum voltage is generated. If the primary current, which is not very large, is broken, the intensity of the spark produced in the secondary winding will be a maximum. In position (D) a similar condition exists to that of position (B) and the value of the voltage will be the same as that in (B). When the armature has moved through 180°, the same condition exists as at zero degree and the voltage generated at this point is zero. Through the first half revolution the primary voltage has varied from zero degree to a maximum and back to zero again. During the second half revolution the action is the same except that the voltage generated is in the opposite direction. This, however, has no effect on the spark produced.

(b) *Primary and Secondary Current.*--In all high tension magnetos the secondary winding is wound on the same soft iron core as is the primary winding. The combination of the core and two windings serves as both a generator and a high tension induction coil. When the primary current is flowing, a magnetic field is set up in the core. The amount of flux is proportional to the strength of the primary current; the greater the current, the greater the flux. When the breaker points open, the primary current ceases, and the flux which is due to the primary current collapses. This collapse of the flux induces the high voltage in the secondary winding. By means of a distributor, this high voltage is lead to the correct spark plug. The secondary current jumps the spark plug air gap serving its purpose of ignition. In order to get the maximum secondary voltage, and hence, the maximum intensity of spark, the breaker points must open as the primary

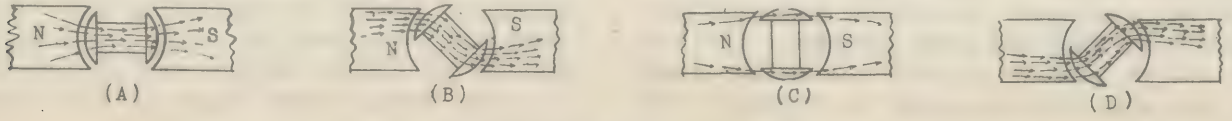


Fig. 40. Rotating Armature Type Magneto (Showing Reversal of Flux)

current reaches the maximum. In practice, it has been found that the primary current reaches a maximum at a few degrees beyond the 90° position; for example, about 96°. This, of course, refers only to the rotating armature type of magneto. In other magnetos, the maximum primary current occurs at other angular positions of the rotating mechanism, the position depending on the construction of the magneto.

(c) ***Type of High Tension Magnetos.*** -- 1. Magnetos vary as to their mechanical construction, but the electrical operation is the same for all. A voltage is generated in the primary winding whenever the flux is increasing or decreasing. The mechanical methods causing the flux to change are as follows:

a. Rotating armature or core with a stationary permanent magnet.

b. Movable sleeve inductor of soft iron feeding the magnetism of a stationary permanent magnet into a stationary soft iron core around which the windings are wound.

c. A movable polar inductor feeding the magnetism from a stationary permanent magnet to a stationary soft iron core around which the windings are wound.

d. Rotating magnet with the soft iron core stationary.

2. These four mechanical means are used in constructing high tension magnetos. This permits the entire ignition system to be constructed as a single unit, making for compactness and light weight.

(d) ***Rotating Armature Type.*** The armature in this type of magneto consists of a spool or bobbin which forms the common core for the primary and secondary currents. The armature rotates and has attached to it the breaker mechanism, distributor, pinion, and a collector ring, see fig. 42. A brush collects the high voltage current from the ring at the proper time and delivers it to the distributor rotor which in turn delivers it to a segment in the distributor which is connected to the correct spark plug. The distributor rotor is driven by a spur gear which engages with the pinion on the armature shaft. The gear ratio is such as will deliver high voltage electricity to the proper number of spark plugs at the correct instants. The rotating armature type magneto is what is commonly known as a two spark magneto. This is because there can be only two reversals of magnetic field per revolution of the armature and, therefore, but two sparks per revolution. The Bosch high tension magneto is of the rotating armature type and is considered one of the best of this class.

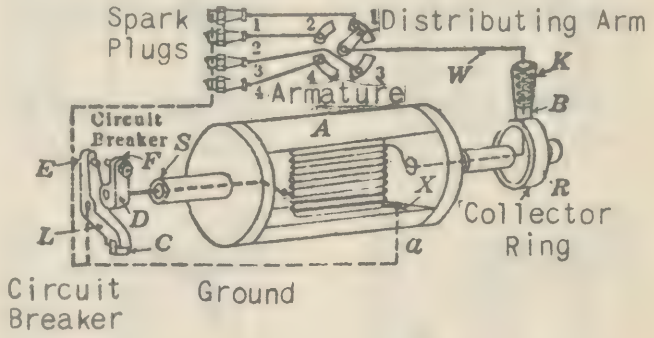


Fig. 42. Rotation Armature Type Magneto.

(e) ***The Sleeve Inductor Type.*** This type of magneto employes a stationary armature of the "spool" or "bobbin" type, about which a sleeve inductor rotates. This inductor forms a path for lines of magnetic force, and serves by its action to reverse their direction through the armature core as the sleeve rotates.

On this type the inductor shaft usually has mounted upon it the breaker assembly and the distributor drive pinion. This is known as a "four spark" magneto, since there are four reversals of direction of magnetic lines of force per revolution of the inductor. Fig. 43 is a sketch illustrating the sleeve inductor principle. In positions 1, 3, 5, and 7 the flux

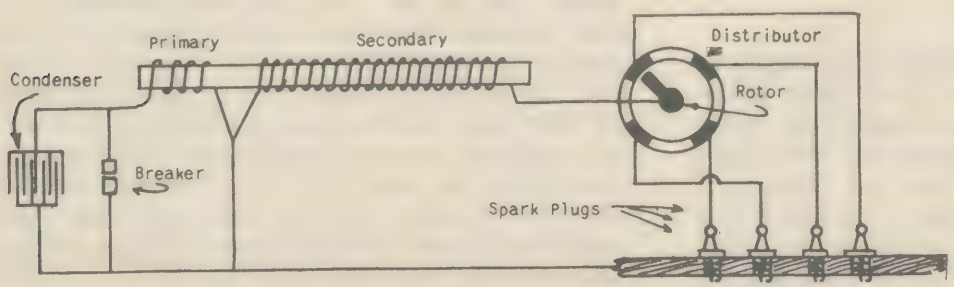


Fig. 41. Circuit Diagram of a High Tension Magneto.

is changing at the maximum rate, and the spark is timed to occur at these instants.

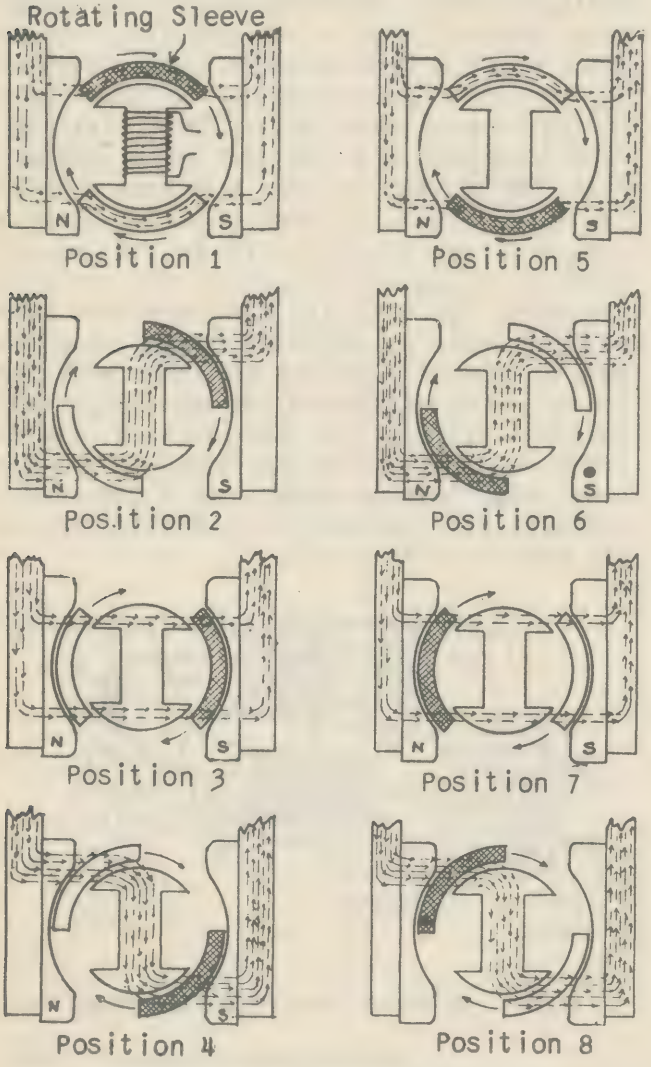


Fig. 43. Sleeve Inductor Magneto.

(f) The *Polar Inductor Type.* The polar inductor type is used on a number of aircraft engines. The Splitdorf "Dixie" magneto is of this type (fig. 44.) The inductor shaft usually has mounted on it the polar inductor, the distributor, the drive pinion, and the breaker operating cam.

(g) The *Scintilla Magneto* has a rotating magnet made up of four poles joined together inside the laminated ends into pairs; the two (2) North or "N" poles making one pair and the two (2) South or "S" poles making the other pair. The rotating magnet revolves between the laminated pole shoes, producing an alternating

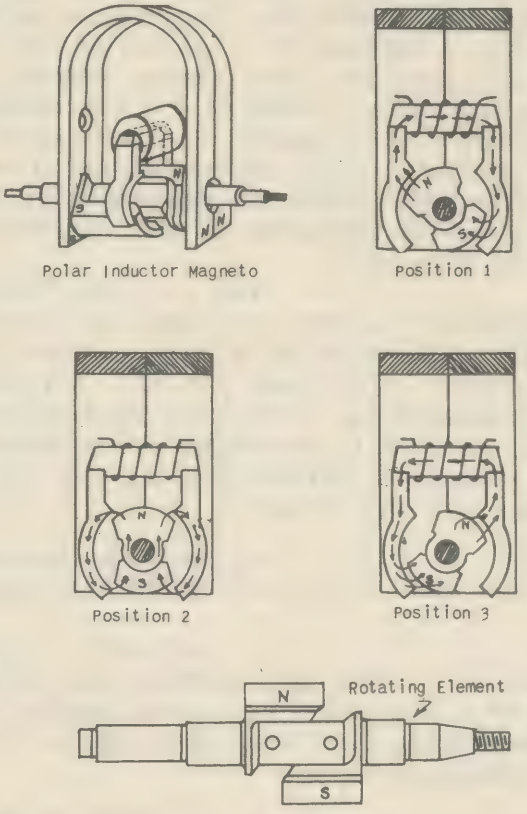


Fig. 44. Splitdorf "Dixie" Magneto (Polar Inductor Type).

field in the core of the coil. The core is fastened between the pole shoes and around the core is wrapped the coil containing the primary and secondary windings. The breaker cam is mounted on the rear end of the magnet shaft and its position is fixed in relation to the magnetic field so that it opens the breaker points at the instant of maximum current production.

(h) A *Condenser* is placed in series with the primary wire coming from the coil to points. It absorbs the initial rush of primary current and prevents abnormal arcing as the points break. It also allows Electro Static Magnetism to pass to ground through its masses. It is the rapidity in which the primary current is done away with which induces the secondary current in the secondary windings of the coil. One end of this winding is grounded to the core of the coil and the other end goes to the distributor which distributes the secondary current.

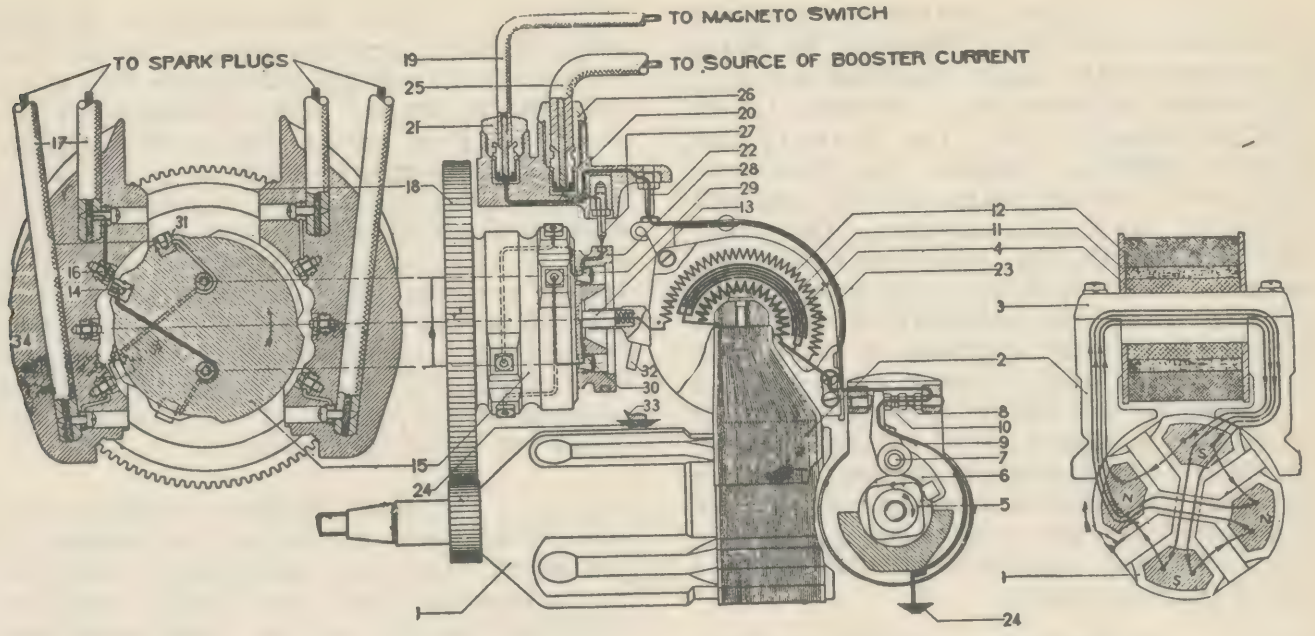
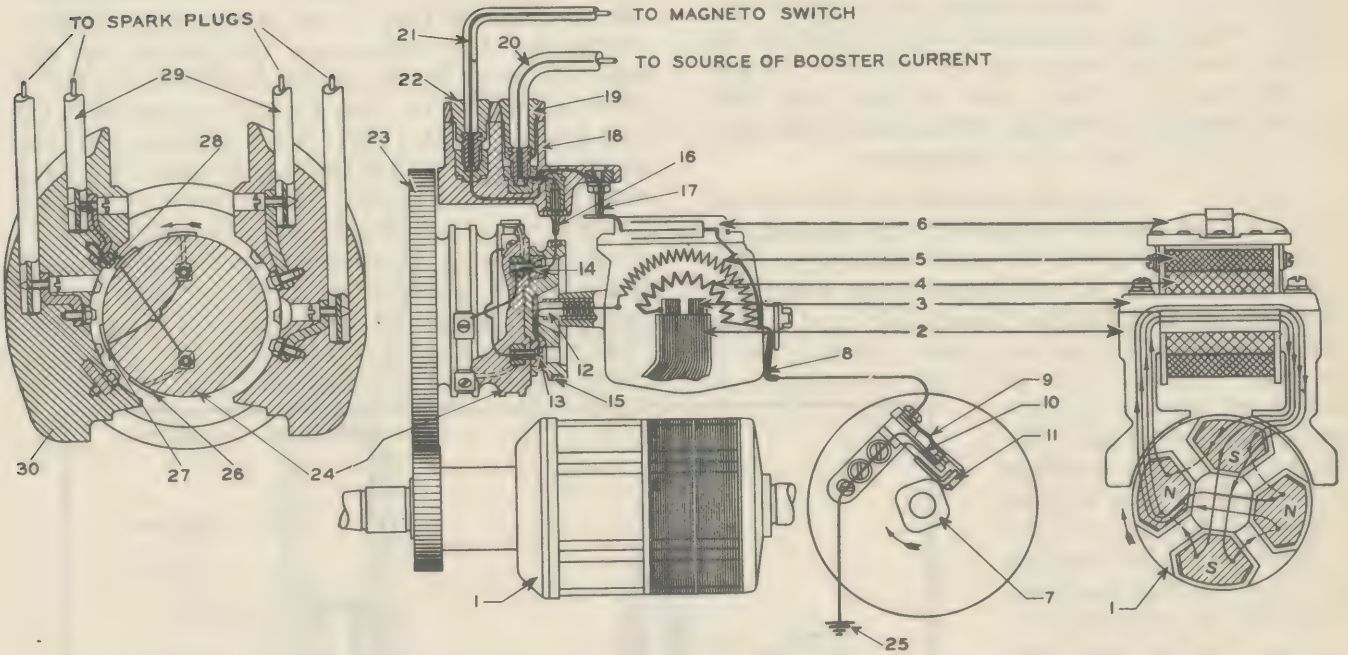


Fig. 45. Scintilla Magneto--Rotating Permanent Magnet Type.



1 ROTATING MAGNET
2 POLE SHOES
3 COIL CORE
4 PRIMARY WINDING
5 SECONDARY WINDING
6 CONDENSER
7 BREAKER CAM
8 PRIMARY CONTACT BRUSH ASSEM.
9 CONTACT BREAKER MAIN SPRING
10 CONTACT BREAKER SUPPORT
11 CAM FOLLOWER
12 HIGH TENSION CARBON BRUSH
13 FASTENING SCREW FOR COLLECTOR RING (IN SECONDARY CIRCUIT)
14 FASTENING SCREW FOR COLLECTOR RING (IN BOOSTER CIRCUIT)
15 COLLECTOR RING FOR BOOSTER CURRENT
16 ELECTRODE FOR BOOSTER CURRENT
17 STUD FOR GROUND CONTACT
18 BOOSTER AND GROUND TERMINAL BLOCK
19 BOOSTER TERMINAL CABLE SCREW
20 BOOSTER CABLE
21 GROUND WIRE
22 GROUND TERMINAL CABLE SCREW
23 LARGE DISTRIBUTOR GEAR
24 DISTRIBUTOR CYLINDER
25 GROUND THRU ENGINE
26 SEGMENT IN DISTRIBUTOR CYLINDER CARRYING SECONDARY CURRENT
27 SEGMENT IN DISTRIBUTOR CYLINDER CARRYING BOOSTER CURRENT
28 ELECTRODE IN DISTRIBUTOR BLOCK
29 IGNITION CABLES
30 DISTRIBUTOR BLOCK

Fig. 46. Schematic Diagram of Electric and Magnetic Circuits: Scintilla Series SF9 (N) and SB9 (N) Magneto.

(i) ***The Distributor Consists of a Block Containing Segments to Which are Connected the Spark Plug Cables*** and a distributor cylinder which revolves inside the distributor block. The distributor cylinder contains a segment for the secondary circuit which bears on the central contact of the collector ring. The outer rim of the collector ring receives the booster current from the electrode to the collector ring. The secondary current and booster current are carried to the proper segment in the distributor cylinder by two segments. The distributor cylinder is geared to the magnet shaft and distributes the spark to the proper segments as it revolves. The booster current segment is so located that it trails the secondary current segment and thus provides a retarded starting spark.

(3) **Comparison of Ignition Systems.**--(a) Both the battery system and the magneto system are reliable and can be made light in weight. Each, however, has characteristic advantages and disadvantages which may influence the decision as to its use. An advantage of a battery type of ignition is that the weight of the entire system is reduced when batteries are required for the other equipment.

(b) The engine can be started without the use of a booster and operation with retarded spark is satisfactory. The motor will idle slowly and more evenly. Changes in the engine speed do not have any effect upon the voltage. There is a constant indication on the instrument board of proper or improper functioning. The distributor and breaker arrangement may be located in an accessible place and the probability of mechanical trouble is reduced because there are few moving parts and the drives are light. The disadvantages of battery ignition are due to fire risk from live wires, more complicated wiring, interference with radio system, and the greater weight when no other electrical equipment is required.

(c) The advantages of magneto ignition are simplicity in maintenance, light weight, less wiring to be shielded to prevent radio interference, no fire risk when the engine is not running, usually unaffected by troubles in the other electrical equipment. The disadvantages of magneto ignition are: a booster is necessary in starting unless the engine can be turned over rapidly; otherwise the voltage goes up as the speed increases, adjustment to provide retarded spark impairs magneto operation, and the location is limited because of the weight of the unit and because the drive is heavier.

(4) **Spark Plugs.**--(a) One of the most vital parts of an ignition system is the spark plug, the function of which is to furnish the small gap across which the secondary current of the ignition system is forced to jump due to the high voltage produced in the secondary circuit, thus setting fire to the mixture of gas and air in the combustion chamber of the cylinder. Spark plug failure in an automobile engine requires the operator to drive to the nearest service station for replacement, putting up with the slight annoyance of the engine misfiring. A spark plug failure in an aircraft engine is a more serious matter. A cylinder missing fire under flying conditions can set-up such vibration stress as to present dangerous possibilities of structural failure, and invariably, an airplane with an engine missing fire must be landed within the maximum time governed by its gliding ability.

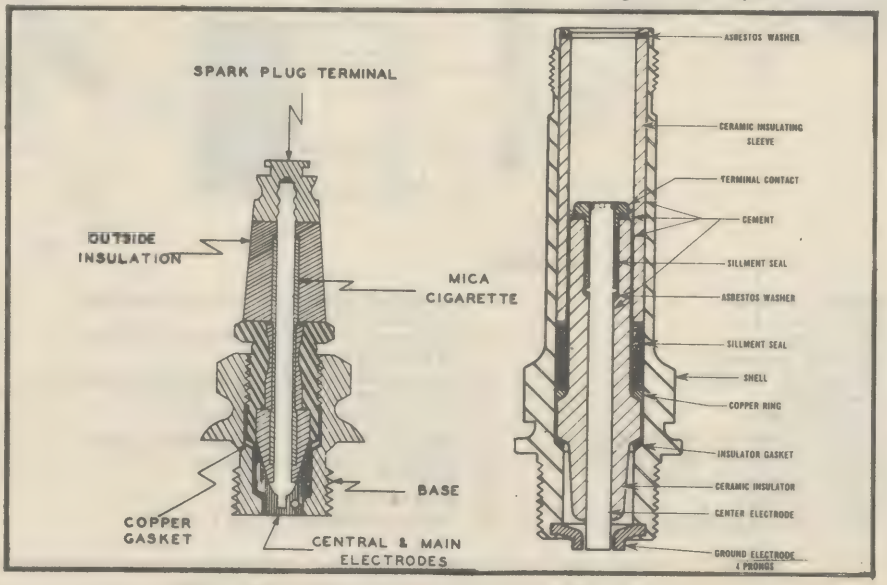


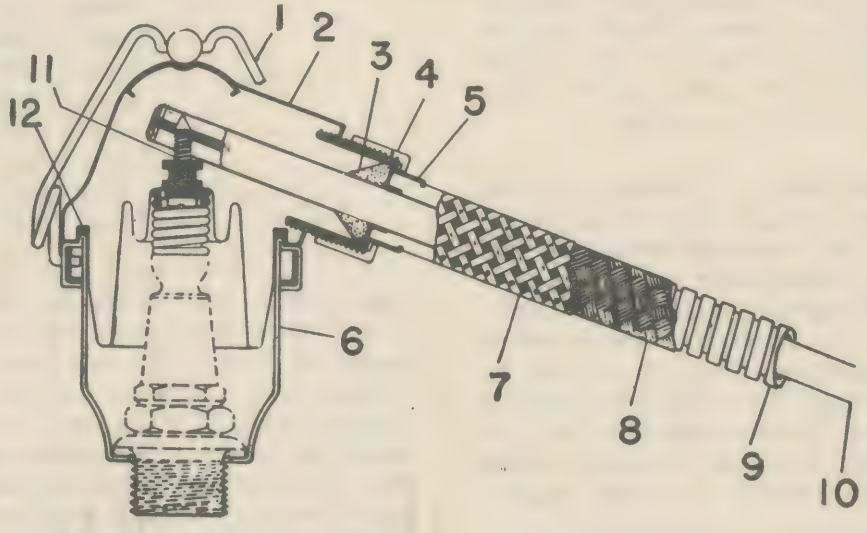
Fig. 47. Aircraft Engine Spark Plug Types.

(b) There are two types of spark plugs in common use, those with ceramic or porcelain insulator cores and those with mica insulator cores. The porcelain type is most common in the automobile and light aircraft engines while the mica type is used most widely in larger aircraft engines.

1. The *Mica Insulated Spark Plug* is more flexible than is the porcelain type and for that reason is not as easily affected by extremes of temperature. Its ability to withstand overheating for short periods of time without failure is most desirable. However, common types of failure to which mica plugs are subject include stretch or creep of the center spindle, compression leakage through the core body, and moisture absorption. Fig. 47 shows a cross section of both the mica and the porcelain type plugs.

2. Spark Plug Troubles.--One of the greatest troubles with which to contend in connection with spark plugs is the cracking of the porcelain insulator due to the change of temperature to which they are subjected. Fouled spark plugs are perhaps the most common of all spark plug ailments. Fouling is caused by using low grade fuel or too rich a mixture, or by reason of the piston pumping oil from the crankcase. These troubles may be temporarily remedied by removing the plugs and cleaning them. The mica plug is mechanically strong and withstands overheating and detonation for long periods without failure; in general, it has a longer life than do the porcelain plugs.

3. Radio Shielding of Ignition Units and Wiring is employed on radio equipped airplanes to absorb the interference given off by the arcing of breaker points and the high tension spark plug gap. The shielding is composed of metal tubing through which the wires are passed. The metal housing or tubing, grounded to the engine, absorbs such interfering signals and passes them into the metal parts of the engine where they do no harm. Magnetos are also shielded and equipped with housing outlets for the ignition cables. Fig. 48 illustrates the Breeze Corporation Shielding Apparatus.



1. Clamp—Spark Plug Shield Clamp
2. Cap—Spark Plug Shield (Assembly)
3. Gasket—Rubber Packing
4. Nut—Coupling
5. Ferrule—Spark Plug Conduit
6. Body—Spark Plug Shield No. 5 takes all plugs up to 1⅝" in length
   Body—Spark Plug Shield No. 6 takes all plugs up to 2" in length
7. Armoring—Phosphor Bronze Ribbon
8. Braid—Tinned Copper Wire
9. Conduit—Aluminum with Asbestos Packing
10. Cable—High Tension Ignition
11. Contact Retaining Screw and Spring Assemb.
12. Gasket Rubber

Fig. 48. Breeze Corporation Shielding Apparatus.

Section II. FUELS AND CARBURETION

1. GASES AND FUELS.--*a. Definition.* ***A fuel may be defined as a substance which, on combination with the oxygen of the air, can be made to produce heat in the form of combustion.*** Hydrogen and carbon alone, or in any of their various combinations, produce large quantities of heat when burned, and constitute our most important fuels for the production of heat and power. Fuels may be classified according to their physical status:

(1) Solid Fuels
(2) Gaseous Fuels
(3) Liquid Fuels.

b. Solid Fuels.--Solid fuels are used extensively for external-combustion engines, such as a steam engine, where the combustion or burning takes place under boilers or in furnaces. They include such fuels as wood and coal. Solid fuels are not used in internal-combustion engines where the combustion takes place inside the engine cylinder, because of their slow rate of burning, low heat value, and numerous other disadvantages.

c. Gaseous Fuels.--Gaseous fuels are used to some extent for stationary internal-combustion engines where an unlimited supply of combustible gas is available. Natural petroleum gas and illuminating gas are two of the most common gases used for this purpose, but they can be disregarded as a fuel for airplane engines as the large space they occupy limits the supply that can be carried. Gaseous fuels are also of comparatively low heat value.

d. Liquid Fuels.--Liquid fuels are in many respects the ideal fuels for use in internal combustion engines. For convenience liquid fuels are divided in non-volatile and volatile classes. The former are the heavy oils which are burned in Diesel-type engines after squirting into the cylinder through a spraying nozzle. The volatile class includes those fuels which are commonly used with a carburetor and which are carried into the engine cylinder with air in an evaporated or partially evaporated condition, such as benzol, alcohol, and gasoline.

e. Petroleum.--(1) As fuels, hydrogen and carbon are seldom available in their natural state, but occur in combination with each other forming compounds known as hydrocarbons. There are many thousands of these compounds in existence and all are classed as fuels. These hydrocarbons are present in large quantities in petroleum, occuring as liquids and gases.

(2) ***Due to the abundance of crude petroleum, and because of the various products which may be extracted from it, it has become our most important source of internal-combustion engine fuel and lubricants.*** The crudes from different fields vary in composition and may be classified according to the location and predominating family of hydrocarbons present as:

(a) Pennsylvania or paraffin base crude
(b) Gulf Coast or asphalt base crude
(c) California or naphthene base crude
(d) Mid-continent or mixed base crude.

f. Straight Run Gasoline.--The fractional distillation process was the first to be developed and produces what is known as straight-run gasoline. In this process the crude is heated to a moderate temperature in a retort to progressively vaporize the various hydrocarbon liquids. The lighter and more volatile compounsd are first vaporized, followed in order by those of higher boiling points. These vapors are then led through condensers which return them to the liquid state. By proper regulation of the vaporization and condensation, the hydrocarbons may be separated into various grades of gasoline, fuel oil, lubricating oil, etc. although further treatment and purification is often necessary. In fractional distillation process, no effort is made to change the chemical nature of any of the fractions. The products formed by distillation are:

(1) **Benzine and Crude Naphtha.**—treated with sulphuric acid and caustic soda to improve color and odor, and redistilled giving largely gasoline.

(2) **Kerosene Distillate.**--treated and redistilled giving largely kerosene.

(3) **Burning Oils.**--burned for heating stills, etc.

(4) **Gas Oil and Fuel Oil.**--part used for fuel oil and part used for absorbing natural gasoline, the remainder cracked to form gasoline and coke.

(5) **Wax Distillate.**--dewaxed in filter press, filtered etc. to give neutral stock.

(6) **Cylinder Stock.**--refined to give bright stock. Various grades of lubricating oils are obtained by blending neutral and bright stock in different proportions.

g. Cracked Gasoline.--(1) The cracking process is employed principally as a means of increasing the yield of gasoline from a given amount of crude. A considerable quantity of oils of a composition between kerosene and lubricating oil is converted into hydrocarbons of lower density and boiling point, which, after treatment, are suitable for fuel purposes. As much as 50 per cent of the crude can be made into gasoline.

(2) The cracking process is a form of destructive distillation in which the crude, or a portion of it, is placed in a sealed retort, and is subjected to a high temperature and high pressure. These conditions serve to break up the chemical arrangement of the heavy hydrocarbon molecules and partially convey the heavier products into cracked gasoline. The fuel thus produced is often superior to many grades of straight-run gasoline in anti-knock value but requires thorough refining with some consequent loss in anti-knock value to make it suitable for storage. The reason for this is that cracking results in a high percentage of unsaturated hydrocarbons which have a tendency to form gum under storage conditions. Some types of cracked gasoline may be stabilized or inhibited from gum formation by the addition of a small quantity of a suitable anti-catalyst.

(3) Cracked gasoline is blended highly volatile straight-run or natural gasoline. A high percentage of the total gasoline production at the present time is the result of the cracking process. Cracked gasoline can also be combined with hydrogen using a suitable catalyst producing a high anti-knock, stable gasoline. The very volatile cracked gases can also be polymerized or combined with themselves to form stable liquid hydrocarbons of very high anti-knock values. These processes are not used very extensively at present. When crude oil supplies become appreciably diminished, it is probable that cracking hydrogenation and polymerization will be more or less universal.

h. Natural Gasoline.--(1) Natural gasoline is obtained from the wet natural gases which originate under the ground from crude petroleum. It is recovered by high compression and absorption in fuel oil. Part is recovered by high compression and cooling to very low temperatures. The most common method of extraction is the absorption process. This is accomplished by forcing natural gas through fuel oil which absorbs the liquid content of the natural gas. The fuel oil is then distilled to reclaim the light fraction which is gasoline.

(2) Natural gasoline is composed largely of hydrocarbons of the paraffin series, butane, pentane, hexane and a little propane. It is light and highly volatile and has a very high vapor pressure until a large part of the propane and butane have been removed by distillation. It is used for blending with heavy, low volatility gasolines to increase their volatility, usually about 10 per cent to 15 per cent being added. If present in a blended gasoline in too high a quantity, it results in vapor lock in the fuel system. Small percentages of propane and butane increase the tendency to vapor lock very rapidly. Natural gasoline represents about 8 per cent of the total gasoline production, but increases the fuel available by another 4 per cent by blending with fuels not volatile enough to use alone.

i. Starting.--The volatility of a fuel is quite important in determining

whether or not an engine may be started when it is cold. In this connection, it is well to know that *gasoline is not readily combustible in its liquid form*, principally because the molecules of the liquid will not mix readily with the oxygen of the air. Gasoline vapor, however, unites quite readily with oxygen, resulting in very rapid combustion when ignited. From this it is evident that an engine fuel should be sufficiently volatile to form combustible vapor at low atmospheric temperatures. The temperature of the 10 per cent evaporated point in the distillation test is an indication of the starting qualities of a gasoline. For easy starting, this point should not greatly exceed 160°F.

j. Vapor Lock.--(1) The characteristic of a gasloine which makes starting easy under low temperature conditions causes vapor lock when the temperature of the fuel rises too high. Under this condition vapors which restrict the liquid flow form in the fuel lines resulting in lean mixtures and the possibility of engine failure. A compromise between the two extremes in volatility of a fuel is generally attained, permitting satisfactory starting characteristics and at the same time probable freedom from vapor lock.

(2) The 10 per cent evaporated point is a fair indication of vapor-locking tendencies, as is the vapor pressure. With improved airplane fuel systems it might be possible to use fuel with a lower 10 per cent point, and with a vapor pressure as high as 10 pounds per square inch at 100° F. instead of the 7 pound maximum now specified. This would result in easier starting as well as in greatly increasing the source of supply of fuel.

(3) Vapor lock is most likely to occur in airplane fuel systems when they reach reduced atmospheric pressures of high altitudes before the fuel has had a chance to cool to the reduced air temperature existing there.

k. Fuel Economy.--Fuel economy depends, to some extent, upon good vaporization and equal distribution of the mixture to the cylinders. For good vaporization, distribution, and economy, a high volatility is indicated.

l. Dilution of the Lubricating Oil.--Dilution of lubricating oil with the heavier ends of gasoline is due to the failure of the heavy fractions to evaporate completely upon entering the cylinder. This condition is exaggerated during the starting and warm-up period and is reduced to a minimum with the application of the proper heat to the manifold and normal operating engine temperatures. A low volatility results in excessive crankcase dilution. Dilution of engine oil is of no consequence in airplane engines due to the high volatility of the fuel and to the high operating temperatures of the engine. The oil dilution system used for cold weather starting is based on this fact.

m. Carbon Formation.--The amount of carbon which is formed in an engine from the fuel used increases with the distillation temperature of the fuel. Because the amount of carbon deposited in an engine varies with a number of other factors, no quantitative value can be given in this connection. Insofar as the fuel is a factor, however, the higher its distillation temperature the greater the amount of carbon deposited under any given condition.

n. Acceleration Characteristics.--Acceleration characteristics, in general, depend upon the lower points of the distillation curve for engines with low temperature manifolds and upon the higher points for engines with high temperature manifolds. With partial throttle opening the pressure in the intake manifold is considerably reduced and the fuel is vaporized quite readily. With the throttle wide open and before engine speed increases, the heavier fractions of the fuel, in the case of gasoline of poor acceleration characteristics, condense or collect on the walls of the intake manifold and form a fuel film. During acceleration a change from the first to the second condition takes place, resulting in leaner mixtures reaching the cylinders, due to the loss to build up the fuel film. In extreme cases the mixture may become so lean that firing back in the carburetor and non-inflammable mixtures would result. Aircraft fuels, due to their high volatility, have excellent acceleration characteristics.

o. Detonation.--(1) Detonation is the nearly instantaneous combustion of the

last part of the charge due to the increased pressure and temperature. The most widely accepted theory now is that as combustion proceeds, the unburned portion of the charge is first compressed by the action of the piston and then by the combined action of the piston and burning portion of the mixture to a point which is above its self-ignition temperature.

(2) Flame travel study by special ionization apparatus has shown that in normal combustion the flame starts out from the spark plug, accelerates to a velocity of from 60 to 80 feet per second, and traverses the rest of the combustion chamber at approximately that speed. When detonation occurs, the flame velocity suddenly increases to about 10 times the normal maximum velocity. Flame study through a quartz window in a combustion chamber indicated that when detonation occurs, self-ignition may sometimes occur at a point ahead of the flame front and travel back to meet the approaching flame front.

(3) Detonation combustion differs from normal combustion. It has a yellow or white flame color instead of a blue or blue-green. In detonation it is believed that the hydrocarbon molecules of the fuel are broken down and that the hydrogen is oxidized in preference to the carbon, *leaving much free carbon to be blown out in the black exhaust which always accompanies detonation.* The brilliant white flame gives up much radiant energy to the carbon-coated cylinder walls, causing the *rise in head temperature always observed.* The loss of energy by radiation and the loss of carbon fuel in the exhaust seem to account for the loss in power experienced.

(4) The intensity of detonation is dependent upon the amount of the unburned portion of the charge which detonates.

(5) The almost instantaneous combustion of the unburned portion causes an extremely high local pressure rise which is transmitted and reverberated through the combustion space at high velocity of sound under those conditions, striking the walls with sufficient intensity to produce the *knock characteristic of detonation.*

(6) Detonation should not be confused with another type of uncontrolled combustion, namely pre-ignition. The latter, as its name implies, precedes the ignition spark, while detonation follows. Detonation seldom occurs earlier than 30° after the spark. It may, if not violent, persist for long periods without adversely affecting the running of the engine. If violent, however, it will cause overheating and prepare the way for pre-ignition to occur.

(7) Continuous detonation results in loss of power and efficiency, overheating, pre-ignition, and may result in failure of cylinder and piston unit parts.

p. Pre-Ignition.--(1) **Pre-ignition, as the term implies, is the initiation of combustion of the charge before, and by some means other than the regular timed spark of the spark plug.** It is caused by the temperature being great enough at some part of the charge to self-ignite it at the pressure existing before the firing of the spark plug. The usual cause is an overheated spot, such as an exhaust valve, center of the piston, the spark plug electrode, or an incandescent carbon deposit. It is a function of the fuel as well as the temperature of the engine. Pre-ignition results in loss of power and efficiency, excessive pressure, increase of crankshaft torsional vibration, and overheating of the engine with possible resultant failure.

(2) When the ignition is timed to occur too early, the result will be the same as if occasioned by pre-ignition. In either case the engine will knock due to high pressures occurring before the end of the compression stroke. Such a knock is called spark knock or pre-ignition knock depending on the cause. Obviously, retarding the spark will eliminate spark knock but will have no effect on pre-ignition.

(3) When pre-ignition occurs after the ignition system has been turned off, it is usually termed after-firing. It is not uncommon in high output, hot running aircraft engines.

q. Factors Influencing Detonation.--(1) *General.*--The nature of the phenomenon called detonation has been the subject of

much conjecture, study, and experimental investigation. It has been found to be a function of both the fuel and engine. Both the design characteristics and operating condition of the engine are influencing factors. The factors influencing detonation are:

(a) Fuel characteristics
(b) Engine operating condition
(c) Mixture temperature
(d) Fuel-air ratio
(e) Throttle opening
(f) Engine design
(g) Supercharging
(h) Valve timing
(i) Timing of the ignition
(j) Combustion chamber
(k) The spark-plug location.

(2) Description of Factors.

(a) *Fuel Characteristics have a decided effect upon detonation.* The tendency of a fuel to detonate is determined by two properties, its self-ignition temperature and its ignition time-lag characteristic. Some fuels, such as alcohol and carbon disulphide, have relatively low self-ignition temperatures but do not detonate readily because of their long time-lag characteristics.

(b) It is characteristic of liquid hydro-carbon fuels that the explosion of a fuel-air mixture raised by rapid compression to its self-ignition temperature takes place only after an appreciable delay or lag. The delay becomes shorter as the temperature of compression is raised. The unburned portion of a mixture charge in a cylinder, compressed first by the piston and later by the expansion of the first part of the charge to burn, is heated to a temperature well above its self-ignition temperature. If it is given time, it will ignite instantaneously and produce a knock. On the other hand, the ignition lag may be long enough, or the engine speed and rate of flame travel high enough, to enable the flame front to spread through the unburned portion and consume it by normal combustion before detonation can occur. The fact that, in a detonating engine, the knocking decreases as speed is increased and becomes more severe as speed is reduced is explained by the existence of ignition time-lag.

(c) *Engine Operating Condition.--Cylinder Cooling.*--Since the temperature of the cylinder walls has considerable effect upon the temperature of the charge before ignition occurs, it also influences tendency to detonate.

(d) *Mixture Temperature increase will increase the tendency of a mixture to detonate.* This tendency is noted in connection with the use of air heaters and hot spots to prevent ice formation on the throttles and aid vaporization of the fuel. Detonation might be expected since the temperature at the end of compressions would be increased, and for any given position of the flame front and rate of travel, the temperature of the unburned portion would be higher. Thus, the lower the mixture temperature the higher the compression ratio may be, within limits, without causing detonation.

(e) *Fuel-air Ratio has a very decided effect on the intensity of detonation and also the tendency to detonate.* For any given engine, other conditions remaining the same, the tendency to detonate is greatest for a certain definite fuel-air ratio. Changing the fuel-air ratio in either direction from the maximum knocking mixture decreases the intensity of the detonation. However, leaner mixtures cause hotter exhaust valves, which may induce pre-ignition. Maximum detonation does not always occur at the same fuel-air ratio for various fuels; it is on the lean side of maximum power, usually near it, and as the proportion of fuel is increased beyond maximum power, the tendency to detonate is further decreased.

(f) *A decrease in Throttle Opening reduces the suction pressure and the compression pressure, will reduce the intensity of detonation, and if carried far enough, will eliminate it.* Furthermore, the products of combustion in the clearance space remain the same and become a larger percentage in the throttled charge. This increase in dilution with residual gases has a marked effect in reducing the detonating tendency of a fuel. Obviously, reducing or eliminating detonation by throttling results in a loss of power in direct proportion to reduction in mass of charge.

(g) *Engine Design--a Compression Ratio* increase will increase the compression temperature and combustion temperature and will decrease the dilution with exhaust products resulting in increased detonation.

(h) *Supercharging*, by increasing the suction and compression presures, and decreasing the dilution with residual gases, will increase detonation.

(i) *Valve Timing has a decided effect on knocking.* A later closing of the intake valve, so that part of the fresh charge is rejected through the intake port, reduces the quantity of charge taken into the cylinder, particularly at the lower speeds where detonation is usually most noticeable. This results in a reduced compression pressure, therefore decreases detonation.

(j) *Timing of the Ignition* to occur late results in the charge being expanded during most of the combustion process, the energy being taken out of both the burned and unburned part tending to hold down the temperature of the unburned part. Obviously, the later the ignition the lower the temperature of the unburned part during combustion and the less the tendency to detonate. This method results in about 1/2 the loss of power incurred when using the throttling method for elimination of detonation. Detonation is usually more severe in one cylinder than in others so that maximum power is usually obtained with spark advance that will produce light detonation.

(k) *The Combustion Chamber* shapes listed in the order of their desirability insofar as detonation is concerned, are sleeve-valve, valve-in-head, L-head, and T-head. The sleeve-valve head is ideal since there is no hot exhaust valve. However, the pistons usually run hotter and may offset the lack of hot exhaust valves.

1. Combustion space design has considerable influence on the tendency to detonate. Hot spots should be avoided. Improvement is obtained by keeping the last part of the charge to burn relatively cool. This may be accomplished by thinning down the portion of the combustion space farthest away from the spark plugs, thereby resulting in greater cooling surface per unit volume. If this thinning is accomplished in such a way as to increase turbulence, still less tendency to detonate will exist; but the engine will by rougher in operation, due possibly to rapid rate of pressure rise without detonation. Turbulence may also be obtained by the use of a shrouded intake valve or a piston with truncated conical crown. Turbulence decreases the tendency to detonate because it speeds up the burning process and thus takes advantage of the time-lag characteristics of the fuel. Also the heat rejection will be increased.

2. The use of aluminum alloy cylinder heads and pistons which have a high heat transfer coefficient usually make possible a higher compression ratio without detonation. Obviously the use of sodium-cooled exhaust valves would decrease the tendency to detonate.

(l) *The Spark Plug in general should be located so as to reduce the length of flame travel to a minimum.* The plug should also be located so that portion of the charge surrounding any hot spot, such as the exhaust valve, will burn early in the cycle. The reason for this location is that, during the combustion process, compressing the unburned part of the mixture next to the hot spot will raise its temperature much higher than when compression is against a cooler surface.

2. CARBURETION.--*a. Definition.*

(1) Carburetion, as applied to the automobile engine, has become quite simplified and adjustments provided for on the carburetor have been reduced to that controlling mixture at idling speed and controlling idling r.p.m. Jets must be cleaned and the float level adjusted occasionally, but beyond that, automobile carburetors need little attention.

(2) Contrasted with the above is the fact that **CARBURETION AS APPLIED TO THE AIRCRAFT ENGINE IS AN ALL-IMPORTANT FACTOR IN ENGINE PERFORMANCE, MECHANICAL LIFE, AND EFFICIENCY OF THE AIRPLANE AS A WHOLE.** Aircraft engine carburetors are subjected to near-peak load requirements 90 per cent of the time, operating under violently changing atmospheric conditions,

and are exposed to continuous vibration which, over a period of a comparatively short time, tends to upset calibration and adjustment.

(3) The air we live in and take for granted must be reckoned with in aircraft engine operation because it has considerable bearing on engine carburetion, particularly the pressure it exerts under varying conditions on the various elements connected with carburetion.

b. Absolute and Atmospheric Pressure.--(1) Air has weight. At sea level the weight of a column of air one square inch in cross section and the full height of our earth's atmosphere, is approximately fifteen pounds. This column of air exerts a pressure on the surface of the earth of fifteen pounds per square inch. If we were to remove this column of air and then measure the pressure on the same square inch of the earth's surface, we would find no pressure existing. The pressure exerted on the surface of the earth in either case is termed the **ABSOLUTE PRESSURE.** The pressure of the atmosphere is also measured by using a mercury column or barometer. At sea level the standard value adopted for atmospheric pressure is 76 centimeters, 29.92 inches, of mercury or 14.7 pounds per square inch. This is also termed one atmosphere of pressure, or **ATMOSPHERE PRESSURE,** at sea level. This pressure or density diminishes with increased altitude.

(2) The effect of **ATMOSPHERIC PRESSURE** on liquids, particularly fuel, oil, and coolants as used in aircraft engines, is most important. To demonstrate the effect of this pressure on liquids, place a tube in a glass of water, then place your finger over the top of the tube and take the tube out. You will note that the water will not run out until your finger is removed, thus allowing atmospheric pressure to enter. This example demonstrates the importance of providing and keeping open adequate vents to outside atmospheric pressure in tanks as well as carburetor chambers as described in this chapter.

c. Combustion of Fuel.--(1) It should be remembered, as has been stated in the past chapter, that liquids will not burn in the liquid state; they must be converted into a vapor or gas and mixed with the proper amount of oxygen before combustion can occur.

(2) **THE MIXTURE OF FUEL AND AIR IS SAID TO BE CHEMICALLY CORRECT WHEN THERE IS JUST SUFFICIENT AIR TO BURN THE FUEL COMPLETELY.**--An insufficient supply of air results in incomplete combustion, while an excess of air insures complete combustion. The mixture is said to be rich in the former case and lean in the latter case. However, if too much excess of either air or fuel is present, the mixture reaches the limit of inflammability and will not burn. Gasoline will burn in a cylinder if mixed with about 8 to 18 times its weight of air. Also as the mixture approaches the limit of inflammability, the rate of burning decreases. This is more pronounced on lean than on the rich side of the correct mixture.

(3) The oxygen, furnished the fuel in order that it can burn, is obtained from the air. Air is a mechanical mixture containing by weight 23 per cent oxygen and 77 per cent nitrogen. The oxygen only is used in combustion of the fuel, the nitrogen being an inert gas and having no chemical effect on combustion.

(4) It is rarely appreciated that an engine producing 1500 hp. consumes approximately 5 tons of air or 5 times its own weight for every hour of operation.

d. Carburetion.--(1) The fuel for an internal combustion engine must be very thoroughly mixed with the air needed for combustion. This is very true of the Otto cycle engine, since thorough mixing of particles of fuel in the air is essential to the rapid and complete explosive combustion of the fuel in that cycle. One of the most effective means of mixing the particles of a liquid fuel with air is by **ATOMIZATION.**

(2) **CARBURETION MAY BE DEFINED AS THE ATOMIZATION AND MIXING OF A LIQUID FUEL WITH AIR IN THE CORRECT PROPORTIONS.**--Atomization is accomplished by the spraying or suction of the liquid fuel through nozzles or jets into a stream of moving air. The suction stroke of an engine reduces the pressure in the cylinder. The pressure drop causes air to flow through the induction system and causes fuel to be

sprayed or sucked from the fuel nozzles. The pressure drop at the fuel nozzle is accentuated by a restricted or venturi section which increases the air velocity and pressure drop at this point.

(3) The degree of atomization depends upon the relative velocity of air and fuel streams, the density of the fuel, and its surface tension. For a given fuel it depends on the relative velocity.

(4) All internal combustion engines except the Diesel engine require carburetion systems to change the fuel into small droplets or to vapor and mix it with the proper amount of air before it enters the cylinders.

e. Vaporization.--(1) The fuel leaves the jet more or less in a stream which breaks up into various sizes of drops suspended in the air stream and which in turn are more finely divided. During this process, vaporization from the surfaces of the drop is taking place which causes the disappearance of the finest particles and the reduction in size of the others. The ideal situation would be to have all the particles vaporized before the mixture leaves the intake pipe directly above or below the carburetor, since this would eliminate the distribution difficulties. Actually, some fuel particles enter the cylinders in liquid form and must be vaporized and mixed during the compression stroke.

(2) The completeness of vaporization depends on the following factors:

(a) *Volatility of the Fuel.*--The more volatile fuels vaporize more readily.

(b) *Temperatures of the Air.*--Higher temperatures increase the rate of vaporization.

(c) *Degree of Atomization.*--A higher degree of atomization presents the maximum amount of surface and the fuel is more readily vaporized. The rate of vaporization can be increased greatly by the application of heat.

(3) **THE INTAKE MANIFOLD OF AN ENGINE DISTRIBUTES THE FUEL MIXTURE FROM THE CARBURETOR TO THE VARIOUS CYLINDERS, AND ALSO ACTS AS A VAPORIZING AND MIXING CHAMBER.**--When a correctly proportioned liquid fuel and air mixture passes out of a carburetor, a certain amount of time is required to vaporize it completely before it enters the cylinders; the intake manifold assists in this purpose.

(4) Intake manifolds for airplane engines are smooth on their inside surfaces and are free from sharp bends in order to eliminate any possibility of retarding the flow of the charge, allowing a greater volume to enter the cylinders and resulting in greater power output.

(5) Some intake manifolds incorporate some type of heating jacket or compartment to assist in fuel vaporization and prevent the incoming vapor from condensing. Manifolds are heated by hot coolant jacketed around the intake manifold, by having a hot oil jacket, or by exhaust gases at hot spots. A combination of hot oil and exhaust gases is a common method. If the incoming charge is heated to excess, the charge is expanded, resulting in low power output due to its low density. Manifolds with fixed heating jackets operate too hot in summer and too cold in winter. Therefore, an adjustable control is usually incorporated.

f. Air-Fuel Ratio.--(1) **General.**--(a) In the time allowed for the mixing and passage of the mixture to the cylinders it is impossible to obtain a thoroughly homogeneous mixture so that, with the correct air-fuel ratio, all the fuel particles will react with all of the oxygen particles in the mixture. In order to consume all of the fuel and oxygen, there must be an excess of neither. Obviously the maximum power will occur when all the oxygen is consumed, which necessitates extra fuel particles. The maximum power mixture will be a rich mixture. The maximum economy mixture will have all the fuel consumed, have surplus oxygen, and will be a lean mixture. The theoretical, useful, air-fuel ratios range from maximum power to maximum economy. Factors which influence these fuel air ratio limits are distribution of the mixture to the cylinders and dilution of the charge with exhaust products.

(b) It is impossible to get absolutely uniform distribution of fuel to the various cylinders of a multi-cylinder engine. Some will receive leaner mixtures than others, and less power than the maximum possible will be developed. Using richer mixtures usually increases the performance by increasing the power output of the starved cylinders, the increase being more than the loss of power from the rich cylinders caused by enriching the mixture.

(c) Dilution of the charge by the exhaust products left in the clearance space reduces the probability of the fuel particles reacting with the oxygen particles. This is not a serious problem under full throttle conditions. Under idling or no-load conditions, dilution is greatly increased and an extra rich mixture is required.

(d) In general, the useful air-fuel ratios are between 11:1 and 16:1, the exact ratio being determined by consideration of power out-put, cylinder temperature, and fuel economy.

(2) **Full Throttle.**--(a) MAXIMUM POWER, REGARDLESS OF FUEL CONSUMPTION, IS OBTAINED WITH A MIXTURE OF FROM 12 TO 14 PARTS OF AIR TO ONE PART FUEL.--(.083 to .071 pound fuel per pound of air).--An excessively lean or rich mixture will not burn properly to produce maximum power. If an engine is operating on too lean a mixture for maximum power and carburetor adjustments are made to increase the amount of fuel in the mixture, the horsepower output will also increase, quite rapidly at first and then gradually until maximum power is obtained. Further increase in the amount of fuel supplied will cause a loss of power, gradually at first and increasing rapidly as more fuel is used.

(b) Cylinder temperatures are greatly affected, especially at full throttle, by the air-fuel mixture ratio supplied the engine, and they increase very rapidly as the mixture is leaned out. Also the cooling system of large output engines may be inadequate under maximum power operating conditions. For these reasons it is often desirable to provide as rich a mixture as can be used at full throttle with only slight loss of power.

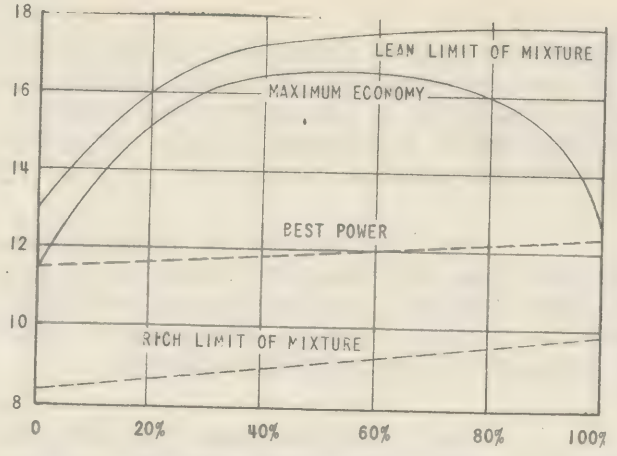


Fig. 49. Air Fuel Ratio.

(c) The relation between power output and mixture ratio is illustrated in fig. 49. It will be noted that the mixture strength for maximum power is not one particular point, but for practical purposes any ratio between 12 to 1 and 14 to 1 gives approximately the same output. In this case the 12 to 1 setting is known as the **RICH BEST-POWER MIXTURE** and the 14 to 1 setting as the **LEAN BEST-POWER MIXTURE.** The **FULL RICH MIXTURE** is generally considered to be slightly on the rich side of the rich best-power mixture.

(3) **Part Throttle (Cruising Speed).**--At cruising speed it is desirable to obtain the maximum power out of a given amount of fuel in order to obtain maximum economy, and a leaner mixture is therefore required. The ratio is about 16 parts of air to one part of fuel (.062 pounds of fuel per pound of air).

(4) **Closed Throttle (Idling).**--(a) When the throttle is closed as at **idling speeds,** the amounts of air and fuel are greatly reduced as compared with wide open throttle conditions, but the amount of exhaust gas left in the cylinders is the same. These gases do not fill the cylinder at atmospheric pressure but expand to fill the cylinder at a much lower pressure. This lower pressure and the greater percentage of exhaust gas in the cylinder at idling or part load result in a tendency of the mixture to burn more slowly, and it is necessary to have a richer mixture.

(b) Fig. 49 where air fuel ratio is plotted against engine speed, illustrates the mixture requirements of an

engine. The best power curve indicates the ratios necessary to obtain maximum power at the various speeds.

g. Carburetor.--A CARBURETOR MAY BE DESCRIBED AS A DEVICE THAT TRANSFORMS LIQUID GASOLINE INTO A DEFINITE AMOUNT OF AIR, THEREBY PRODUCING A GAS THAT IS HIGHLY COMBUSTIBLE WHEN COMPRESSED AND IGNITED. The more intimately the oxygen, nitrogen, and fuel particles are mixed in the correct proportions, the more efficient the fuel mixture will be. The carburetor consists essentially of a main air passage through which the engine draws its supply of air, with mechanisms to control the fuel level, amount of fuel discharged, and amount of mixture admitted to the cylinders.

(1) **Essential Parts of a Carburetor are as follows:**

(a) The Float Chamber
(b) The Strainer
(c) Main Metering System
(d) Idling System
(e) Economizer System
(f) Accelerating System
(g) Mixture of Altitude Control.

(2) **The Float Chamber** is a reservoir for fuel so arranged that the fuel can be delivered into the air charge

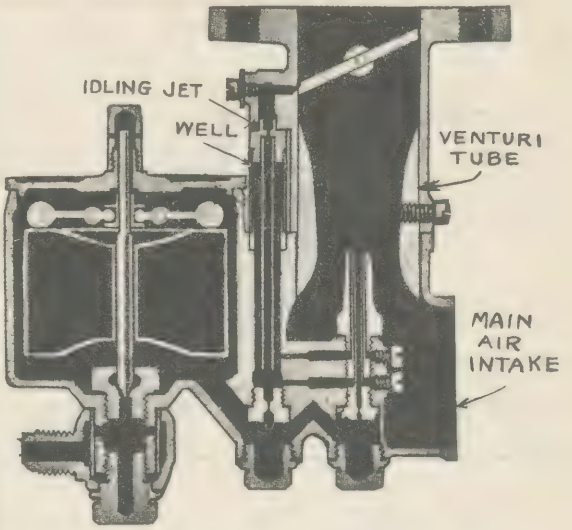


Fig. 51. Cross-Section of a Zenith Carburetor.

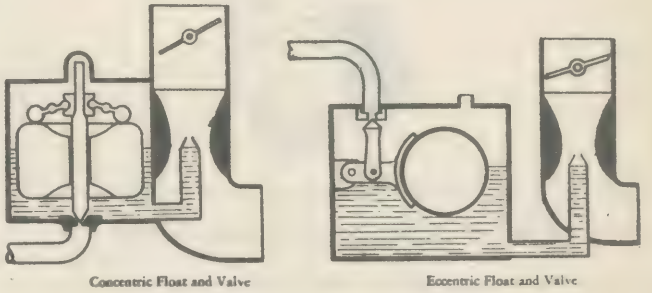


Fig. 52. Carburetor Floats.

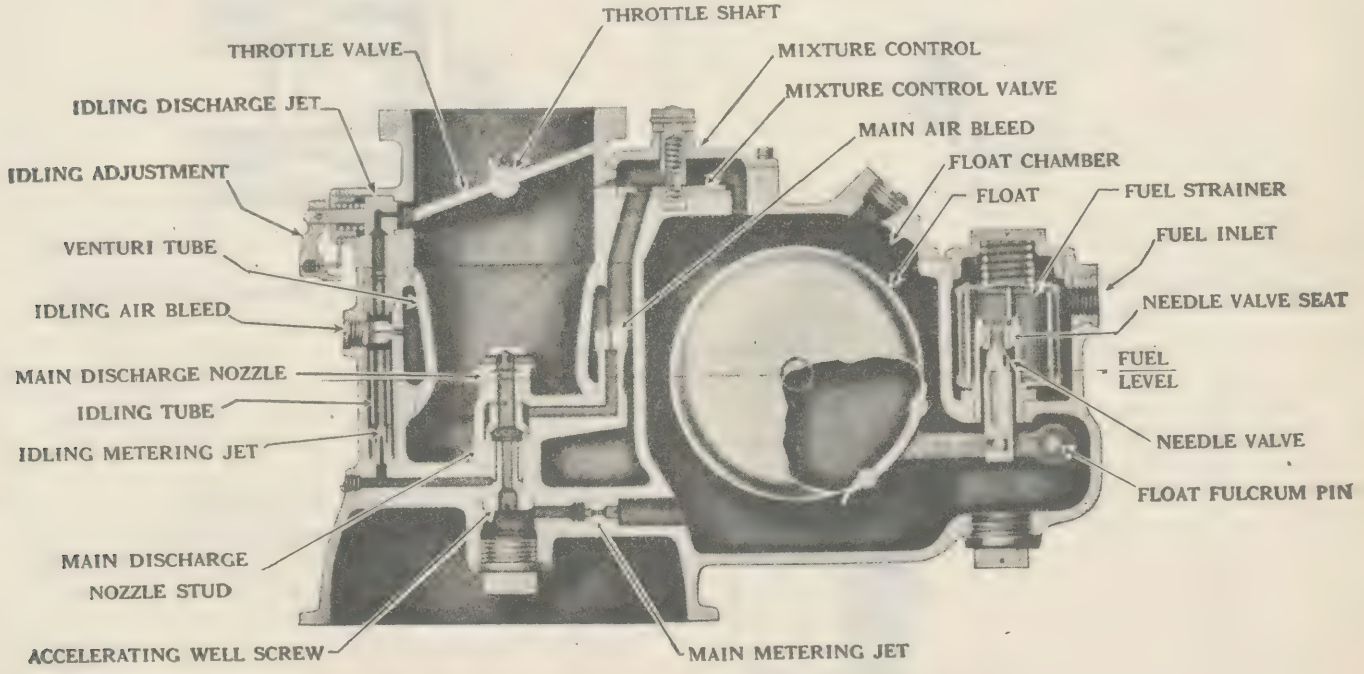


Fig. 50. Cross-Section of a Stromberg Carburetor.

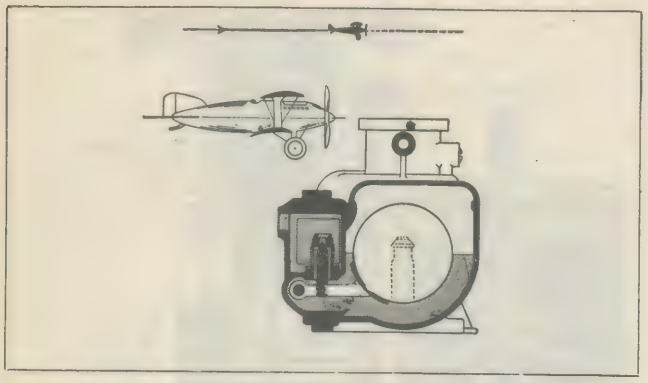


Fig. 53. Level Flight, Normal Feed to Jet.

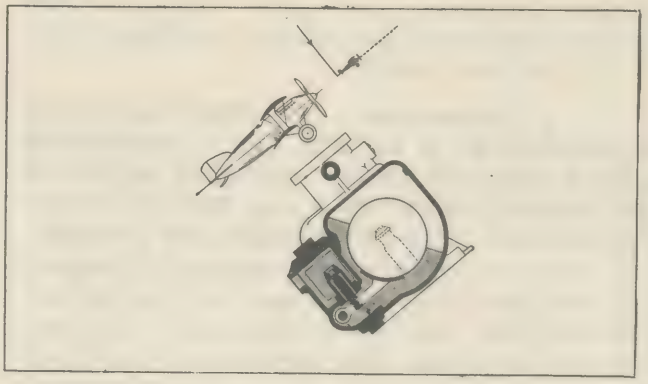


Fig. 56. Steep Climb Following a Dive.

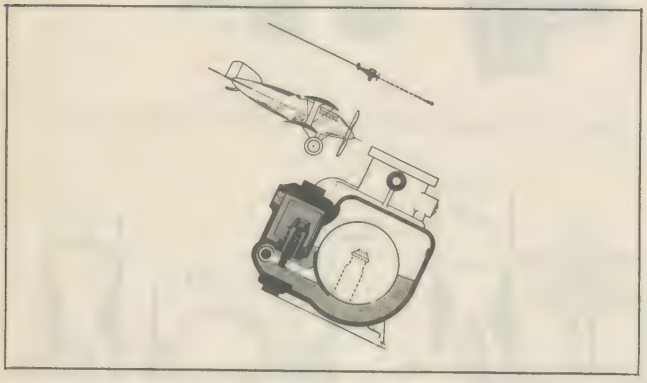


Fig. 54. Dive, Normal Feed to Jet.

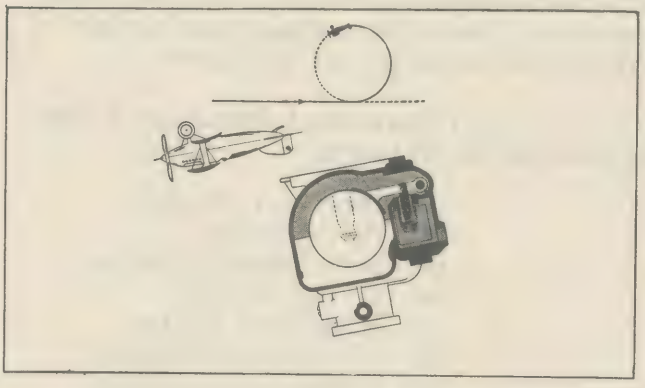


Fig. 57. Loop, without Stall, Normal Feed as Long as Pilot Is Hard Against Seat.

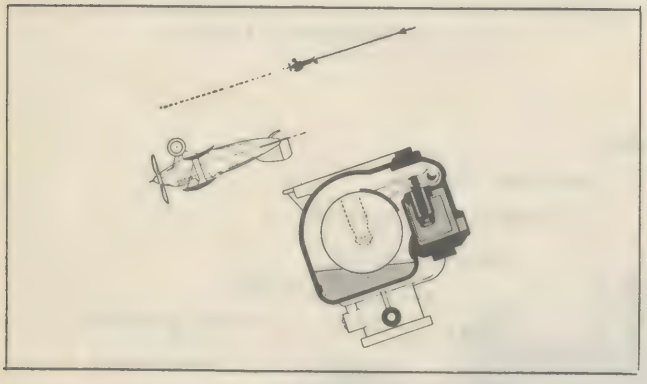


Fig. 55. Continuous Flight Upside-Down No Fuel to Jet.

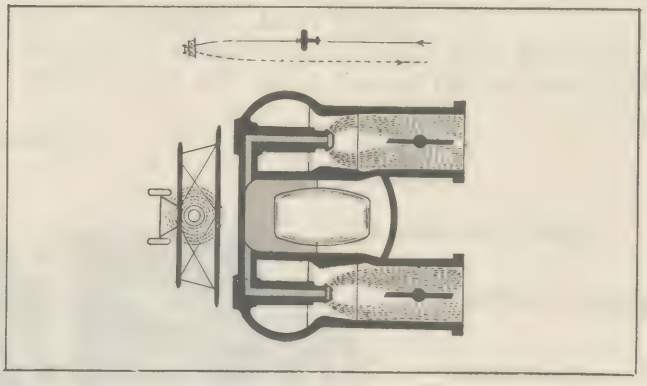


Fig. 58. Vertical Bank, Normal Feed to Jet.

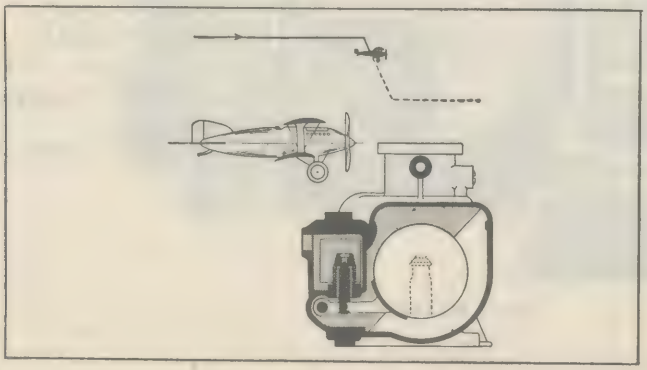


Fig. 59. Violent Drop, Interrupted Feed to Jet.

continuously and at a constant level. In an aircraft carburetor the fuel should be subjected to no other force than the suction resulting from the air flow in the venturi. A constant level reservoir is provided between the main gasoline tank and the metering system of the carburetor. The construction of two types of float mechanism is shown in fig. 52. With no fuel in the carburetor the float takes a position leaving the needle valve open. As fuel is admitted from the supply line, the float rises and closes the valve as the fuel reaches the level indicated by the horizontal dotted line. When the engine is running and fuel is being drawn out of the float chamber, the valve does not alternately open and close but takes an intermediate position so that the valve opening is just sufficient to supply the required amount of fuel to keep the level constant.

(a) The operation of the float mechanism and the position of the fuel during different maneuvers of the airplane depend not only upon gravity, but also upon the motion and position of the airplane. The motion of the airplane involves inertia, and, during certain movements, centrifugal force, while the position of the airplane determines the position of the outlets of the float chamber relative to the earth. It is necessary that the float mechanism operate positively at all angles and positions where power is demanded for the engine, and that it should not permit the leakage of gasoline in other positions. Figures 53, 54, 55, 56, 57, 58 and 59 indicate the position of the fuel in the float chamber for the various maneuvers of the plane.

(b) The pilot is acted upon by the same forces that affect the fuel in the float chamber. If he is resting on the seat, forced to lean hard against the back or sides of the seat, or tending to slide forward, the float action will be normal although the fuel will shift in the same direction. These conditions exist in a climb, dive, side slip, skid, barrel roll, or a loop executed without stalling, as indicated. It will be noted that the passage leading to the metering system is covered with fuel in all positions so that the fuel feed to the carburetor is not interrupted.

(c) If the position or motion of the airplane is such that the pilot tends to be lifted off the seat and be supported by the belt, the same forces will cause the fuel to go to the top of the float chamber. This can occur when a violent gust of wind forces the airplane down so quickly that the pilot leaves his seat. In such case the fuel will take the position shown. Although the fuel is forced to the top of the float chamber, the outlet to the metering system is not uncovered. If the engine is fitted with a fuel pump which is supplied with fuel in the inverted position, the fuel line pressure is exerted on the metering system and an excessive amount of fuel may be supplied to the engine.

(d) In some carburetors two floats are used, both attached to the same lever and float needle valve, one ahead and one to the rear of the fuel discharge jet. As the carburetor is inclined, the fuel level rises on one float and goes down on the other, but its position relative to the discharge nozzle is not changed.

(e) The fuel level in an air craft carburetor is below the bottom of the main discharge nozzle holes. In order to maintain the pressure in the float chamber approximately the same as that existing in the air intake, vent passages are provided which open into the air intake.

(3) **The Strainer** consists of a fine wire mesh, cipher cone-shaped or cylindrically-shaped, located in a place in the carburetor where the gasoline will have to flow through it before passing through the needle valve into the float chamber. Refer to fig. 50 for general location. Strainers are usually removable so that they can be easily cleaned.

(4) **The Main Metering System** maintains a constant air-fuel mixture at all throttle openings throughout the power range of engine operation.

(a) Parts.

1. A venturi

2. A metering jet which measures the fuel drawn from the float chamber.

3. A main discharge nozzle including the main air bleed;

4. A passage leading to the idling system.

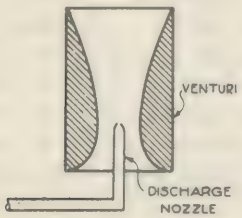


Fig. 60. Venturi.

(b) Functions

1. Proportions the fuel-air mixture;

2. Decreases the pressure at the discharge nozzle;

3. Limits the airflow at full throttle.

(c) The air flow through an opening of fixed size and the fuel flow through an air bleed jet system respond in substantially equal proportions to changes in pressure. An approximately uniform mixture proportion throughout the power range of engine operation can be maintained by locating the discharge nozzle of the air bleed system in the center of the venturi so that both are exposed to the suction of the engine in the same degree. Such an arrangement together with a constant level chamber is shown in fig. 61.

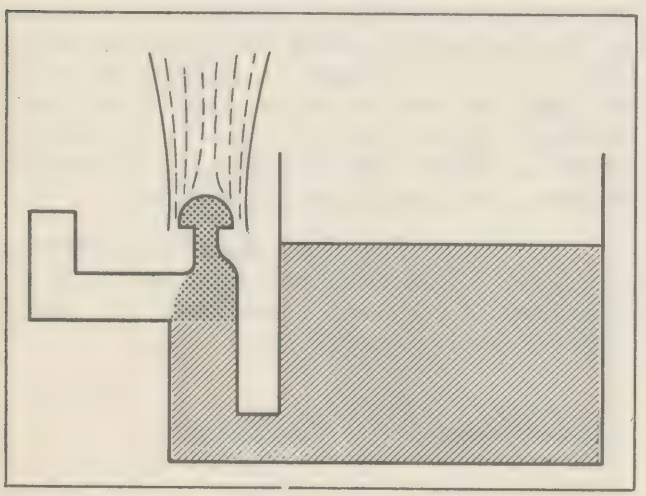


Fig. 61. Air Bleed Principle on Stromberg Carburetor.

(d) The full power output from the engine requires that the manifold suction or partial vacuum above the throttle valve be between 0.4 and 0.8 pound at full engine speed. From the standpoint of metering and spraying the fuel, it would be desirable to use a suction several times this. The venturi fulfills this requirement. It is possible to obtain, on a jet located on the central portion, several times the suction existing in the intake manifold, thereby maintaining a low manifold vacuum. High manifold vacuums result in low volumetric efficiencies.

(e) As the venturi tube limits the air capacity of the carburetor, it is made in different sizes which may be selected according to the requirements of the engine to which the carburetor is fitted.

(f) It is generally believed that a simple plain jet in a carburetor of fixed size tends to deliver a continuously richer mixture as the engine suction and air flow increases, but this is not actually true. Under the sections of medium and high engine speeds, as carburetors are now built, a plain jet will give a fairly uniform mixture; but coming down to low speeds and suctions, the jet delivery falls off markedly in relation to the air flow. This is due to the fact that some of the suction force is consumed in raising the fuel from the float level to the jet outlet (to avoid overflow with the motor not running, the jet must stand a safe distance above the fuel level) and in overcoming the tendency of the fuel to adhere to the jet tip. At low suction the fuel clings to the metal of the jet and tears off intermittently in large drops. The discharge from a plain fuel jet is, therefore, retarded by an almost constant force which is insignificant at high suction, but which perceptibly reduces the flow at low suction.

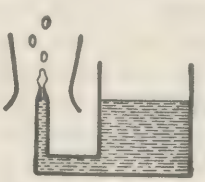


Fig. 62.
Fuel Adhering to Nozzle Tip at Low Suction.

(g) AN AIR BLEED IN A CARBURETOR IS THE PRINCIPLE OF LIFTING AN EMULSION OF AIR AND LIQUID TO A HIGHER LEVEL THAN THE LEVEL OF THE LIQUID IN FLOAT CHAMBER WITHOUT SIPHONING THE LIQUID INTO THE INDUCTION SYSTEM. The application of the "Air Bleed" principle overcomes this difficulty. The suction may be great enough to lift a liquid above its level without drawing any of it away. If a tiny air hole is pricked in the side of the straw above the liquid surface and the same suction applied as before, bubbles of air will enter the straw and the liquid will be drawn up in a continuous series of small slugs or drops.

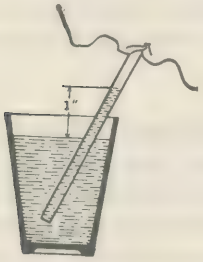
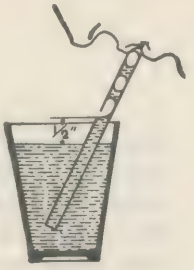


Fig. 63.
Suction Lifting Liquid without Drawing Any of it Away.

(h) Since there is still a distance through which the liquid must be lifted from its level before the air begins to pick it up, the free opening of the straw at its bottom prevents very great suction being exerted on the air bleed hole or vent, just as too large an air opening in proportion to straw size would reduce the section available to lift the liquid.

Fig. 64.
Suction Drawing Liquid by Action of the Air Bleed.



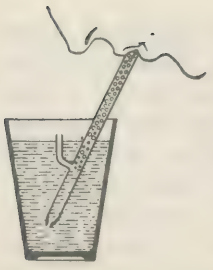
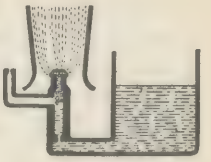


Fig. 65.
A Better Application of the Air Bleed.

Fig. 66.
Carburetor Nozzle with Air Bleed.



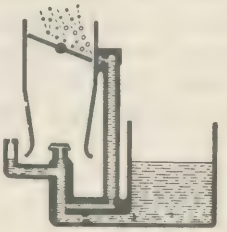


Fig. 67.
Air Bleed, Venturi, and Idling Passage.

(i) In the drawing, the air is taken in slightly below the liquid level and a restricting orifice is placed at the bottom of the tube, with the result that a finely divided emulsion of air and liquid is formed in the tube. Mixture proportion can be modified for high and low speeds as desired by the proper selection of dimensions of the air bleed and emulsion channels.

(5) **Idling System.**--(a) The main metering system does not entirely meet the requirements of carburetor service, because at low speeds the air flow is not sufficient to carry the fuel from the jet to the throttle valve. At the same time, however, there is a very high suction on the intake manifold side of the throttle valve and a fuel feed is arranged to deliver into this region of high suction. To utilize this suction, a complete discharge system in miniature is used, with fuel metering jet, air bleed, and discharge nozzle opening into a small air passage around the throttle valve formed by a slot in the idling discharge jet. Fig. 68 (a) shows an idling system in diagrammatic form.

(b) The method of mixture graduation in this small carburetor element is entirely different from that of the large one. The greatest suction in the intake manifold above the throttle is at lowest speeds, when the least air is taken in and, consequently, when the least fuel is needed. As the engine speed increases and more fuel is needed, the suction in

the manifold decreases. The idling system, therefore, does not meter under the suction existing in the intake manifold, but instead is controlled by the suction existing in a small intermediate chamber or slot formed by the idling discharge nozzle and the wall of the carburetor at the edge of the throttle valve, and having openings into the barrel both above and below the throttle. In this way suction increases as the throttle is opened so that the correct fuel feed can be maintained throughout the low speed range.

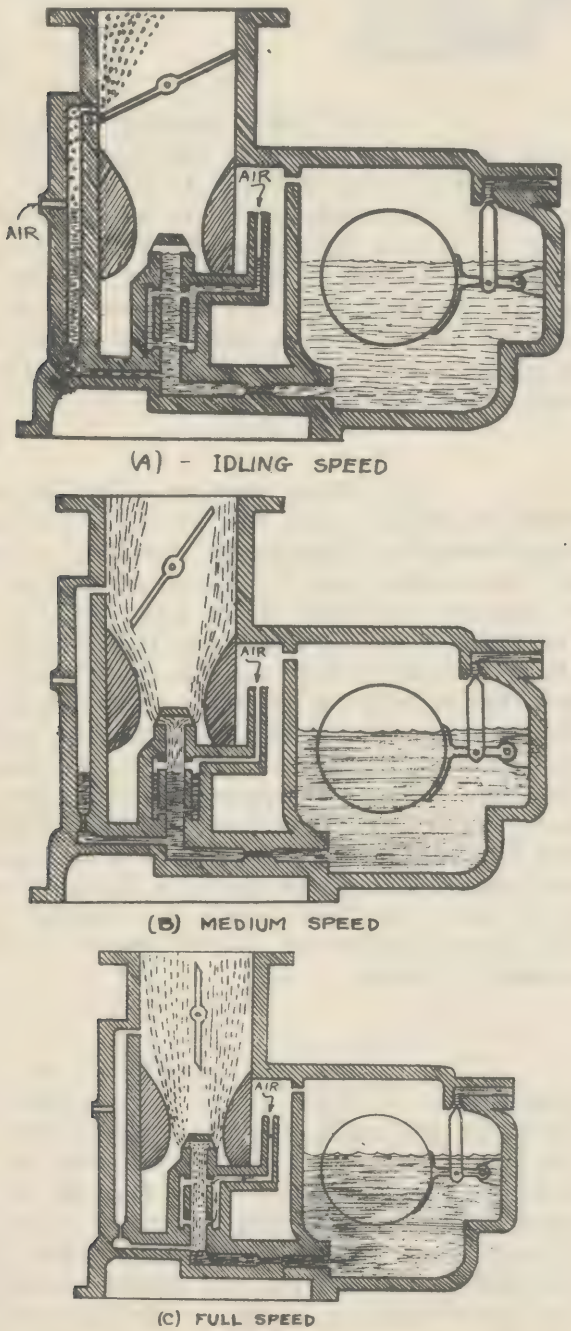


Fig. 68 Stromberg Carburetor.

(c) ***WHEN THE ENGINE IS STARTED, THE IDLING JET FURNISHES GASOLINE, WITHOUT AIR BLEED, FROM THE SPACE AROUND THE IDLING TUBE.*** This provides a rich mixture for starting. No fuel is furnished by the main metering system. With the engine idling and up to about one-fourth speed, fuel mixed with air from the idling air bleed is furnished by the idling discharge nozzle. The accelerating well is still almost full. As the engine speed increases from one-fourth to one-half, the main jet comes into action and fuel mixed with air is furnished by both systems. Some fuel still remains in the accelerating well. Above one-half speed all the fuel is furnished by the main discharge and economizer system, and the idling system acts as an auxiliary air bleed to the main metering system.

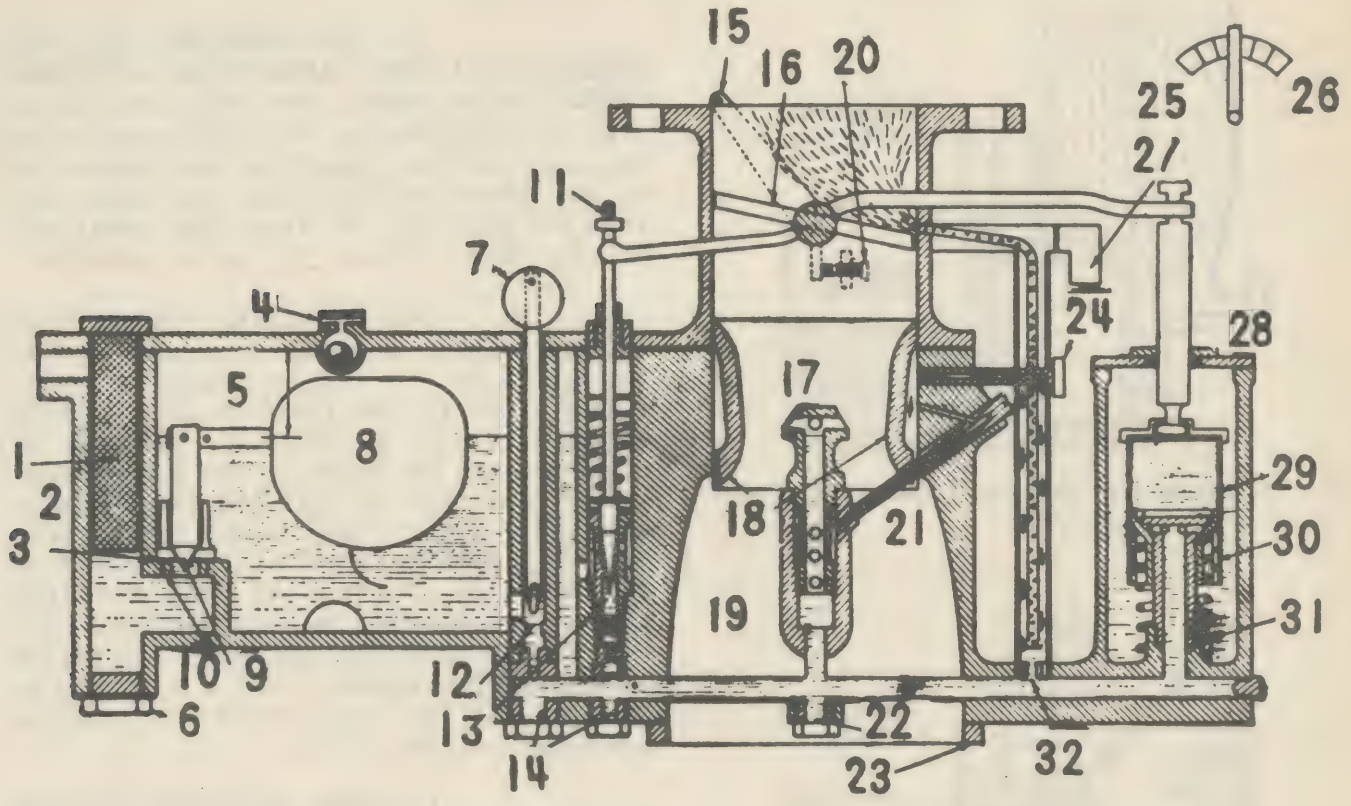
(6) **Economizer System.**--(a) It is desirable to have a lean mixture for maximum economy at cruising speeds and a much richer mixture for maximum power at full throttle. In order to obtain this change in mixture as the throttle is opened, various types of economizers are used. These in their present form are really enriching devices. In other words, carburetors so equipped are set normally for their leanest mixture delivery and enriched for power requirements.

(b) Economizing Systems as used by the army are classed as:

1. Needle Valve Economizer
2. Piston Type Economizer

(c) The needle valve economizer consists of a needle valve which is opened by the throttle at a predetermined throttle position, and permits a quantity of fuel, in addition to that furnished by the main metering jet, to mix with the air in the carburetor.

(d) The piston type economizer operated by the throttle is shown in figs. 70 and 71. The lower piston acts as a fuel valve, preventing any flow of fuel through the system at cruising speeds, while the upper piston acts as an air valve and permits air to flow through the separate economizer discharge nozzle at part throttle. As the throttle is opened, the lower piston uncovers the fuel port so that the



1. Carburetor strainer or screen
2. To raise lower fuel level
3. Remove/add washers
4. Vent to atmosphere
5. Fuel level 7/8" below parting surface
6. Drain plug
7. Needle mixture control - up, rich down, lean needle shown in full rich position
8. Float
9. Float needle valve
10. Needle seat
11. Needle type economizer
12. Main jet
13. Economizer jet
14. Jet sediment wells
15. Throttle arm
16. Throttle valve
17. Discharge nozzle
18. Venturi
19. Air Bleed well
20. Idle speed adjustment
21. Main air bleed
22. Sediment well
23. Carburetor air horn mounting flange
24. Idle air bleed
25. Rich
26. Lean
27. Idling mixture adjustment
28. Section of float chamber
29. Accelerating pump cylinder
30. Piston
31. Return spring
32. Idling jet.

Fig. 69. Schematic Drawing of NAR Series Single Barrel, Stromberg Carburetor--Idling Position.

fuel is drawn through the system and out the discharge nozzle. The upper piston cuts off the air bleed to the economizer nozzle, thus increasing the suction on the fuel jet.

(7) *Accelerating System.*--(a) All carburetors are equipped with either an accelerating pump or accelerating well which discharges an additional quantity of fuel into the carburetor air stream when the throttle is opened suddenly. This results in a temporary enrichment of the mixture, which gives a smooth and positive acceleration of the engine.

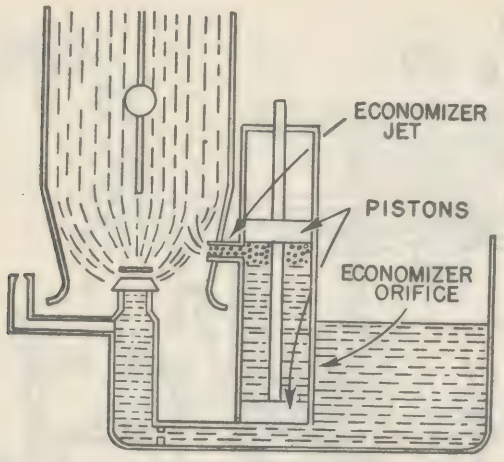


Fig. 70. Piston Type Economizer Operating at Full Throttle.

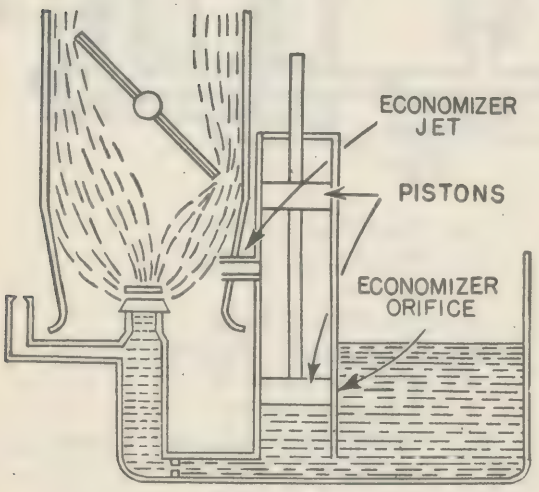


Fig. 71. Piston Type Economizer Operating at Cruising Speed.

(b) With partial throttle openings the pressure in the intake manifold is considerably reduced, and the fuel is vaporized quite readily. At low speeds with throttle wide open, the heavier fraction of the fuel condenses or collects on the walls of the intake manifold and forms a fuel film. During acceleration a change from the first to the second condition takes place, resulting in leaner air-fuel mixtures reaching the cylinders due to the loss of fuel to build up the fuel film. This effect, together with the lag due to inertia of the fuel, results in the mixture becoming so lean that firing back in the carburetor and non-inflammable mixtures result. As the wall film is built up and the inertia of the fuel is overcome, the mixture returns to the desirable ratio.

(c) ***THE ACCELERATING WELL CONSISTS OF A SPACE AROUND THE DISCHARGE NOZZLE.*** Holes connect the emulsion passage with the accelerating well. The upper holes are near the fuel level and are uncovered at the lowest suctions that will draw fuel from the main jet, so that they admit air all the time the main jet is in operation.

(d) At idling speeds very little throttle opening is required and the vacuum in the intake manifold relatively high. If the throttle is suddenly opened, air will be drawn in, not only to fill whatever cylinder is on the suction stroke, but also to fill the intake manifold. This quick rush of air temporarily creates a high suction at the main discharge nozzle, brings the main metering system into operation, and draws extra fuel from the accelerating well. The engine speed then increases, due to throttle opening, and the main metering system continues to function.

(e) ***THE ACCELERATING PUMP DELIVERS A POSITIVE AND DEFINITE CHARGE OF FUEL REGARDLESS OF THE SUCTION EXISTING IN THE CARBURETOR.*** It delivers this charge as a momentary spurt of fuel followed by a sustained discharge lasting several seconds. For this reason the accelerating pump is usually preferred to the accelerating well principle in aircraft carburetors.

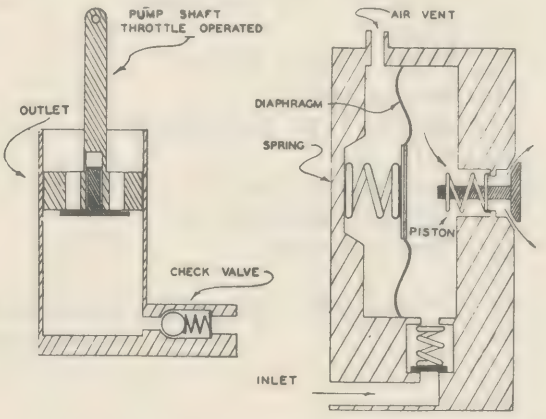


Fig. 72. *Accelerating pumps.*

(f) There are several common types of accelerating pumps. Fig. 72 illustrates two types. One consists of an inverted cylinder having a stem at the upper end that is operated by the throttle. Within the cylinder is a piston which

slides on a hollow stud screwed into the main body casting. The upper end of this stud is shaped like a small poppet valve with several holes in the wide face of the valve leading into the center hole of the stud. The valve seat is in the piston, which is held up against the valve by the pressure of a spring. The center hole of the stud connects with a passage leading to the main discharge nozzle, or to a separate discharge nozzle located just below the edge of the throttle valve. The assembly is mounted in the float chamber.

(g) When the throttle is closed, the cylinder is in the top position and the space within is filled with fuel. As the throttle is opened rapidly, the cylinder is moved down; the pressure of the fuel above the piston forces it down, thus opening the valve so that fuel under pressure is forced out the main discharge nozzle. The spring then forces the piston up, so the fuel discharge continues even after the throttle has reached the wide open position. If the throttle remains open, the piston soon reaches the valve and stops all flow of fuel through the accelerating system. As the throttle is closed, fuel is drawn into the cylinder through the clearance space between the piston and cylinder. This arrangement of filling the cylinder provides automatic regulation of the fuel charge, depending upon the speed of throttle opening. If it is opened slowly, the fuel passes through the clearance space back into the float chamber, and the engine receives no accelerating charge.

(8) **Mixture or Altitude Control.**

(a) As the airplane ascends in altitude the atmosphere decreases in pressure, temperature, and density. The weight of air charge taken into the unsupercharged engine decreases with the decrease in air density, cutting down the power in about the same percentage.

(b) This also occurs above the critical altitude in supercharged engines. In addition, the mixture proportion delivered by the carburetor is affected; the mixture becomes richer at a rate inversely proportional to the square root of the change in density of the air.

(c) All airplane engine carburetors incorporate a device known as a mixture control by which the mixture can be controlled to a certain extent while in flight. The purpose of the mixture control is to:

1. Prevent the mixture from being too rich at altitudes.

2. Economize on fuel during engine operation in the low power range where cylinder temperature will not become excessive with leaner mixture.

(d) Mixture controls may be classified according to their principles of operation as:

1. Back suction type. Reduces the effective suction on the metering system.

2. Needle type. Restricts the flow of fuel through the metering system.

3. Airport type. Allows additional air to enter the carburetor between the main discharge nozzle and the throttle valve.

(e) *THE BACK SUCTION OR FLOAT SUCTION ALTITUDE CONTROL* method of operation may be understood by referring to figs. 73, 74, 75. This drawing of a simple carburetor has an air entrance, a fuel nozzle, and a float chamber fuel supply with two openings at the top, one connected to the same suction as the fuel nozzle and the other connected to a region of no suction (outside atmospheric pressure.) These connections have valves "B" and "A" respectively which can be opened or closed.

(f) Referring to fig. 73, if the valve "B" is closed and the valve "A" is wide open, there is the ordinary and usual condition of carburetor action with suction on the main nozzle and no suction, but simple atmospheric pressure, on the float chamber. This condition exists when the mixture control is in the full rich position.

(g) If, as shown in fig. 74, the valve "B" were open and valve "A" closed, no fuel would flow because the suction would be the same on either side of the main nozzle fuel stream and there would be no force acting to cause it to

flow. The fuel would therefore simply take the level shown. This corresponds to the extreme lean condition that could be obtained with this type control in which there would be no fuel flow at all. In actual construction, the suction connection is taken from a location of lower suction as shown by the dotted lines in fig. 75, so that with the valve "A" entirely closed, some fuel would flow. This condition usually corresponds to a correction for 30,000 feet altitude.

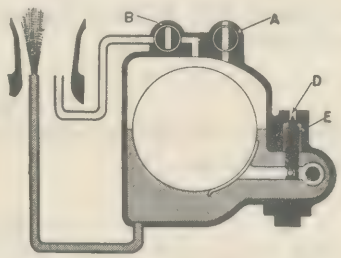


Fig. 73.

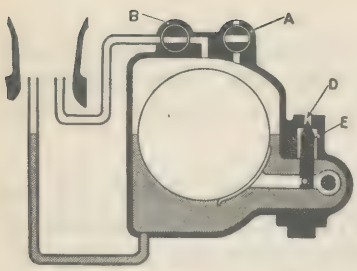


Fig. 74.

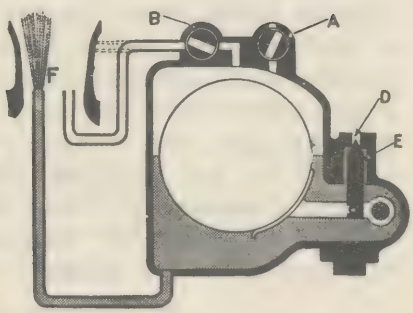


Fig. 75.

(h) Fig. 75 shows how an intermediate condition may be obtained. If the valves "A" and "B" were partially open, the pressure in the float chamber will not be equal to the full suction on the nozzle, nor will it be atmospheric pressure, but somewhere between, depending upon the relative openings at "A" and "B." The rate of fuel discharge will consequently be between those of fig. 73 and fig. 74. And so long as valves "A" and "B" are left in one position, the pressure on the float chamber will always be the same percentage of the suction at "F" regardless of how the suction at "F" may vary, so that the action of any setting is uniform at all operating speeds. "D" and "E" indicate the float needle valve seat and needle valve respectively.

(i) In this type of control the desired range is so limited that the valve "B" may be dispensed with and a small hole of fixed size used instead, the total regulation then being accomplished by motion of the valve "A." In order that the action of the control is not too sensitive, the closure of the valve must be rapid at first and then more gradual. This is obtained by the use of a float disc valve working upon an elongated opening or slot as shown in fig. 76. This type control valve is built as an integral part of the carburetor.

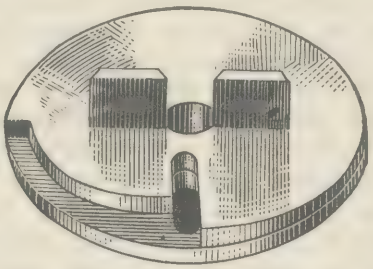


Fig. 76. Altitude Control Valve Disc and Plate.

(j) ***THE NEEDLE VALVE TYPE*** of mixture control is used to restrict the fuel passage to the main discharge jet. With the mixture control in the full rich position, the needle is in the fully raised position, and the fuel is accurately metered by the main metering jet in the fuel passage. To lean out the mixture the needle is lowered into the needle valve seat, thus reducing the fuel supply to the main discharge jet. A small by-pass hole from the float chamber to the fuel passage permits some fuel to flow, even though the needle valve is completely closed. The size of the by-pass opening determines the range of control.

(k) ***THE AIRPORT TYPE*** of mixture control consists of an air passage leading from the area between the venturi tube and the throttle valve to atmospheric pressure. A butterfly valve located in this passage is manually controlled from the cockpit. By opening this valve, additional air that has not been charged with the fuel vapor may enter the carburetor. It also decreases the velocity of the air coming through the venturi tube by lowering the

suction in the intake manifold. fig. 29 shows the Airport Control By-Pass.

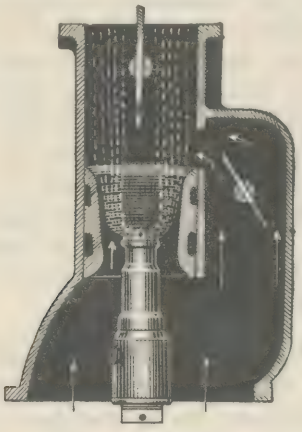


Fig. 77. Air Port Control By-Pass.

(9) **Automatic Mixture Control.**

(a) While formerly the mixture control was manually operated only, the more modern aircraft carburetors incorporate provision for automatic mixture control with increasing altitude. Automatic controls may utilize the needle valve principle, back suction principle, or throttle the air intake to the carburetor. In the latter case the control will regulate power output within certain limits in addition to its function as a mixture control.

(b) In the back suction and needle valve system the control may be directly operated by the contraction and expansion of a pressure sensitive evacuated bellows through a system of links. This is the simplist form for automatic control and is used today with considerable success, proving both reliable and accurate in service.

(c) In some cases or systems direct control by the bellows may not be practicable and it becomes necessary to adopt a serve piston operated by engine oil pressure as the motive force. The function of the bellows in this instance is to regulate the valves or ports which control the oil flow to the serve piston.

(d) Automatic controls often have more than one setting in order to give the proper mixture for both high speed and cruising operation. Provision for manual control is usually incorporated in case of failure of the automatic control.

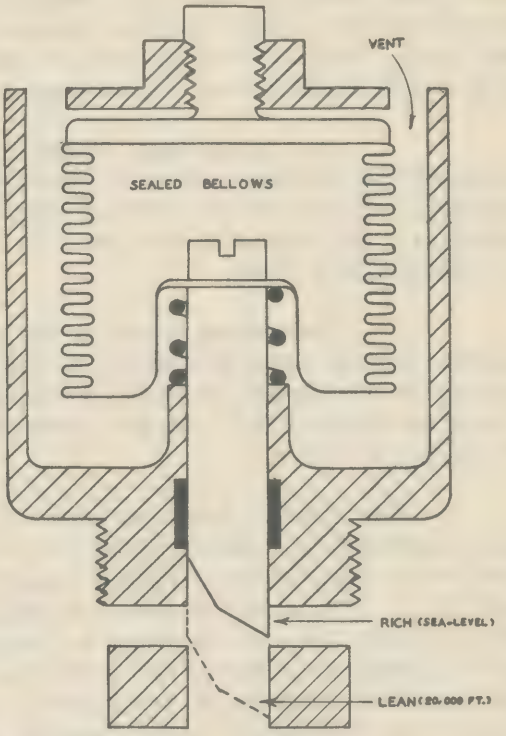


Fig. 78. Automatic Mixture Control.

(10) **Adjustment of Mixture Control.**--(a) A common method of adjusting a manually operated mixture control, is to observe the change in r.p.m. as the control is moved. By careful observation of the r.p.m., a fair indication of mixture strength can be obtained. This method is not applicable to engines having constant speed propellers, since in this case variations in mixture ratio will not change the r.p.m.

(b) The following expressions are applicable to manual adjustment of mixture control when a propeller that can be locked in a fixed pitch position is used. The use of a constant speed propeller of the type that cannot be locked in a fixed pitch position and in which the extreme pitch positions result in engine speeds outside the normal operating range in flight, requires the use of an instrument for the mixture control.

(c) *FULL RICH* is the setting of the mixture control lever in the position giving maximum fuel flow.

(d) *BEST POWER* (sometimes termed Maximum Power) is the setting of the mixture control lever which, with a

given fixed throttle setting, results in a maximum engine r.p.m. at the leanest fuel flow; i.e., further leaning of the mixture would cause a decrease in engine r.p.m.

(e) ***RICH BEST POWER*** is the setting of the mixture control lever which, with a given fixed throttle setting, results in the maximum engine r.p.m. at the richest fuel flow.

(11) *Smooth Operation.*--To obtain the setting for Smooth Operation the setting for Best Power is obtained and the mixture enriched until engine speed drops from 20 to 30 r.p.m.

h. The Zenith Carburetor.--(1) The Zenith Carburetor, shown in fig. 79, has become very popular for airplane engine use because of its simplicity, as mixture compensation is secured by a compound nozzle principle that works very well in practice. The discharge arrangement consists of two concentric jets, one of which delivers an increasing amount of fuel with increase in air-flow, and the other jet of a type that will deliver a constant amount of fuel to the air stream regardless of the air-flow.

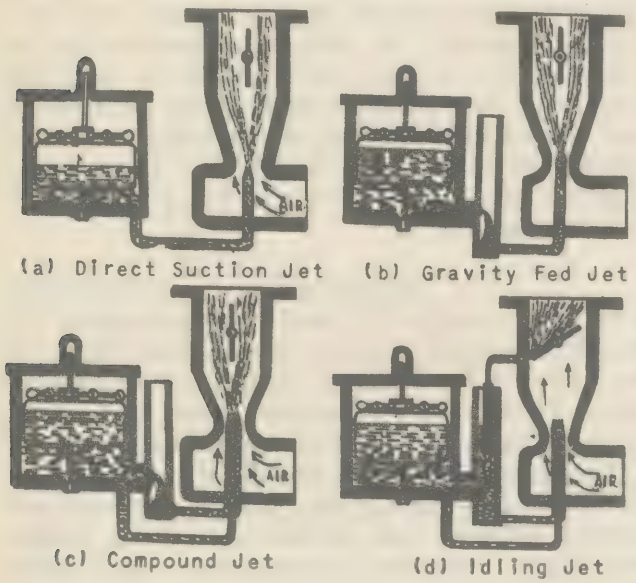


Fig. 79. Zenith Carburetor.

(2) The constant flow jet which gives a leaner mixture as the suction increases serves to balance the direct suction jet which gives a richer mixture as the suction increases. The direct suction jet is shown at A. The gravity-fed or constant flow jet is shown at B. At C we see the two combined, such combination serving to give correct mixtures at medium and high speeds. At low engine speeds the suction below the throttle is not sufficient to draw fuel from either of the main jets, and in order to obtain fuel at idling speeds, the idling jet shown at D is used. At idling speeds the fuel is drawn up through the idling jet, because in this position of the throttle the suction above the throttle is much greater than that below the throttle.

i. The Stromberg Injection Carburetor.--(1) **General.**--The Stromberg Injection Carburetor is a radical departure from previous practice and is the result of a long program of research and extensive test. It represents a wholly new approach to the problem of aircraft engine fuel feed, in that it employs the simple, long used and trouble-proof method of ***metering the fuel through fixed orifices according to air venturi suction***, combined with the new fuction of atomizing the ***fuel spray under positive pump pressure.*** Many inportant advantages have resulted from this construction, among them the following:

(a) No ice formation from vaporization of fuel.

(b) Complete maneuverability. Gravity and inertia effects are negligible.

(c) Accurate metering at all engine speeds and loads, independent of changes in altitude, propeller pitch, or throttle position. ***(Completely Automatic.)***

(d) Pressure atomization of the fuel resulting in increased economy, flexibility, and smoothness.

(e) Simplicity and uniformity of settings.

(f) Protection against fuel boiling and vapor lock.

(2) **Units.**--Understanding of the construction, inspection and repair of the new carburetor is made easier by the fact it is sub-divided into separate units, each of which has its individual duty and function.

(a) ***THE THROTTLE UNIT*** of the Injection Carburetor is quite similar to that used with conventional float type

carburetors. It has a butterfly type throttle valve, a large and a small venturi, provision for mounting an automatic mixture control unit and a flange for mounting the Regulator Unit. A manually operated valve to by-pass the Automatic Mixture Control and make it inoperative is also included in the Throttle Body design. The suction at the throat of the small venturi is a measure of the amount of air entering the engine. This suction, when corrected by the Automatic Mixture Control for changes is air density, becomes a measure of mass air flow and is applied to the air diaphragm of the Regulator Unit to regulate the fuel metering pressure (or head) across the fixed jets in the fuel control unit.

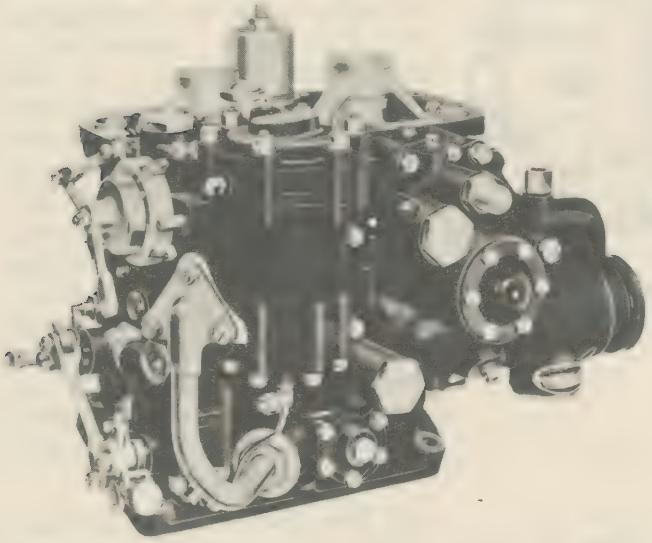


Fig. 80 Down Draft

(b) ***THE AUTOMATIC MIXTURE CONTROL*** consists of a sealed metallic bellows operating a contoured valve. The bellows is filled with a measured amount of an inert gas to make it sensitive to temperature as well as pressure changes. The valve, therefore, has a predetermined position for each air density encountered in flight.

(c) ***THE REGULATOR UNIT*** automatically adjusts the fuel pressure across the metering jets, and, therefore, the fuel flow, in proportion to the mass air flow through the Throttle Body. The unit is made up of an air diaphragm, a fuel diaphragm, and a balanced fuel valve, all mounted on one stem supported on suitable guides. Fuel enters through a strainer, passes through the balanced valve to one side of the fuel diaphragm chamber and then to the jets in the Fuel Control Unit. A vapor separator is provided in the strainer chamber to prevent vapor entering the regulator.

(d) ***THE FUEL CONTROL UNIT*** attached directly to the Regulator contains the metering jets, an economizer valve, an idle needle, and a manually operated mixture control and mixture selection valve. The economizer valve is operated by an air diaphragm and provides enrichment in proportion to mass air flow through the carburetor. The idle needle is mechanically connected to the Throttle and controls the mixture throughout the idle range of speeds. The manual mixture control provides full rich, automatic rich, automatic lean, and idle cut-off positions.

(e) ***AN ADAPTER*** of some sort with a constant pressure discharge nozzle is supplied with metered fuel direct from the Fuel Control Unit. This fuel is sprayed under pressure across the face of the supercharger.

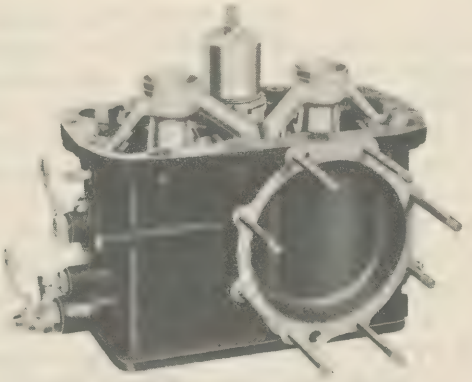


Fig. 81. PD-12 Throttle Unit.

(3) **The Throttle Unit.**--(a) It will be noted the throttle unit follows conventional carburetor lines in that it comprises a throttle, a venturi tube system for developing suction, and a group of impact tubes for collecting the average entrance pressure. A venturi tube loses greatly in efficiency when a fuel spray is

delivered within it. In this system, in which such disturbance is absent, it has been possible to obtain *more than twice the metering head* per unit resistance obtainable in previous carburetors, with a very marked increase in metering range and also in accuracy of mixture regulation.

THROTTLE UNIT

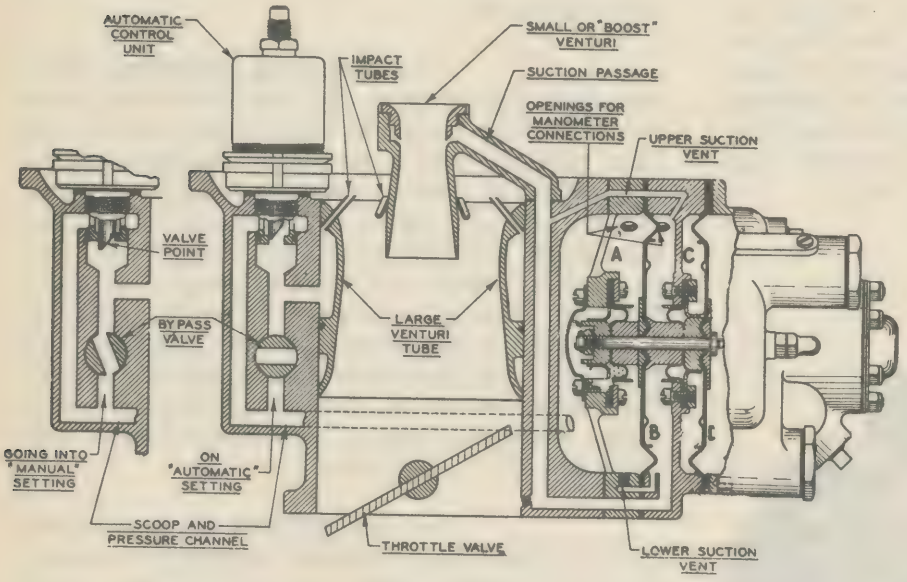


Fig. 82. Section Through Throttle Unit and Through Part of Regulator Unit.

(b) Adjustment for change in air density is accomplished by the Automatic Mixture Control Unit reducing the pressure in Chamber "A," so as to reduce the A minus B difference which is the metering head on the jets, (see fig. 82). To achieve this, the pressure in Chamber "A" is balanced between a small control suction vent at the bottom, which leads from "A" to the venturi suction spaces "B," and a larger "scoop and pressure" channel, normally open at sea level to scoop pressure as received through the impact tubes. As the density of the air entering the air scoop is reduced by increase of altitude, the Automatic Mixture Control bellows expands, lowering the Automatic Mixture Control valve point, and reducing the pressure force in Chamber "A."

(c) For possible check of the mixture ratio during flight by manual adjustment, an Automatic Mixture Control by-pass valve is sometimes provided. However, a disc or other form of valve may be used instead of the cylindrical cock shown schematically at fig. 82. This is usually connected serially with the "lean" and "rich" cruise positions of the pilot's mixture control lever.

(d) It will be noted that the passages out of Chambers "A" and "B" are arranged so that any rain taken in through the large venturi impact tubes will be drawn out at once.

(4) **THE AUTOMATIC MIXTURE CONTROL UNIT** is a metallic bellows responsive to variations in temperature and pressure operating a contoured valve. It is used to maintain the correct fuel air mixture ratio in a carburetor operating under conditions of varying air temperature and pressure, such as result from changes in altitude. This is accomplished by the unit automatically varying the metering pressure on the jets to furnish a flow of fuel proportional to the mass air flow to the engine.

(a) The sealed metallic bellows is filled with nitrogen and an inert oil. The nitrogen provides the temperature response; the oil dampens vibration. As the density changes, the bellows expands or contracts moving the tapered needle in the seat, which changes the size of the orifice and regulates the flow of air past the unit, thus controlling the effective metering pressure on the jets.

(b) The Automatic Mixture Control Unit is used on all models of Stromberg Injection Carburetors and many of the float type. The Unit is furnished in several types having variations in the covers, screens, size of the threads on the mounting bases, and different tapered needles. The same bellows are used in all types.

(c) The tendency of flexible metallic bellows of low hysteresis to

Fig. 83.

respond to engine vibration frequencies has been eliminated by the construction shown. The inner diameter of the bellows is given a small clearance around a cylindrical center sleeve and the space between is filled with a measured amount of chemically inert fluid having a low viscosity change with temperature. Under vibration each convolution of the bellows acts as a dash pot, both hysteresis and synchronous vibration are eliminated, and the endurance of the device in service has proved quite satisfactory.

(d) The bellows and springs are carefully calibrated to insure the proper response rates. The valve points are specified by letter and number to designate their taper.

(e) The complete calibrated unit is a self-contained assembly which is screwed into the throttle body.

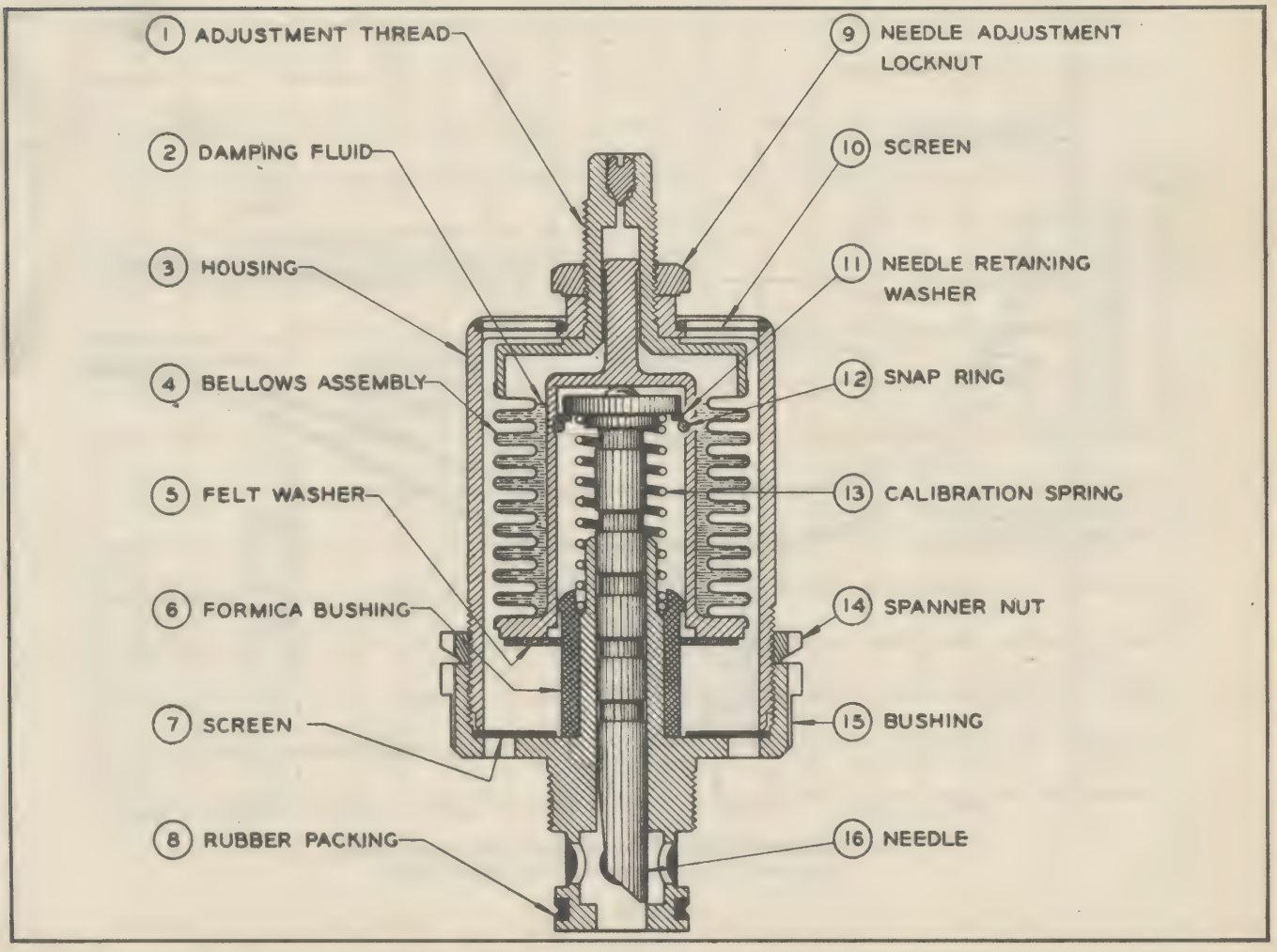


Fig. 84. Automatic Mixture Control Unit.

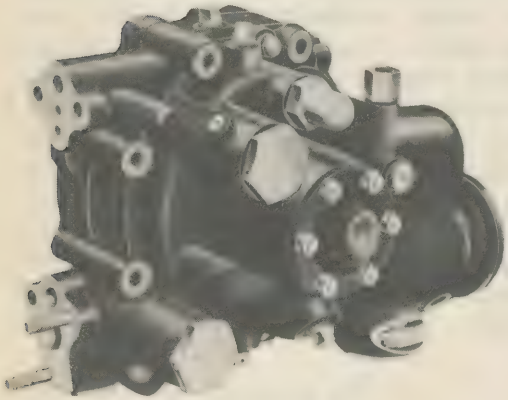


Fig. 85. Regulator Unit.

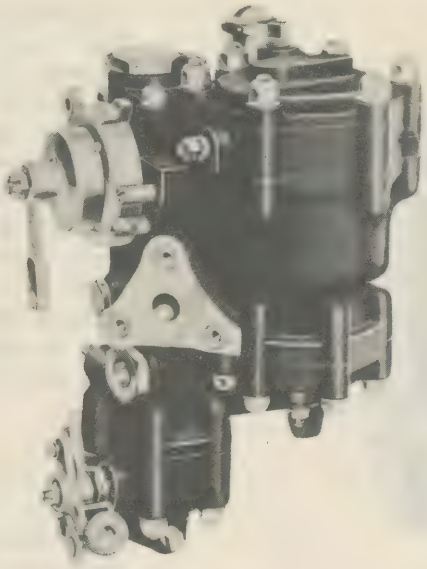


Fig. 86. Fuel Control Unit Showing Manual Mixture Control and Idle Adjusting Screw.

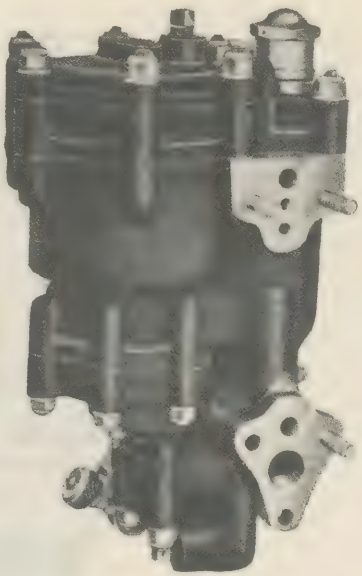


Fig. 87. Fuel Control Unit Showing Fuel Passages In Connecting Flanges.

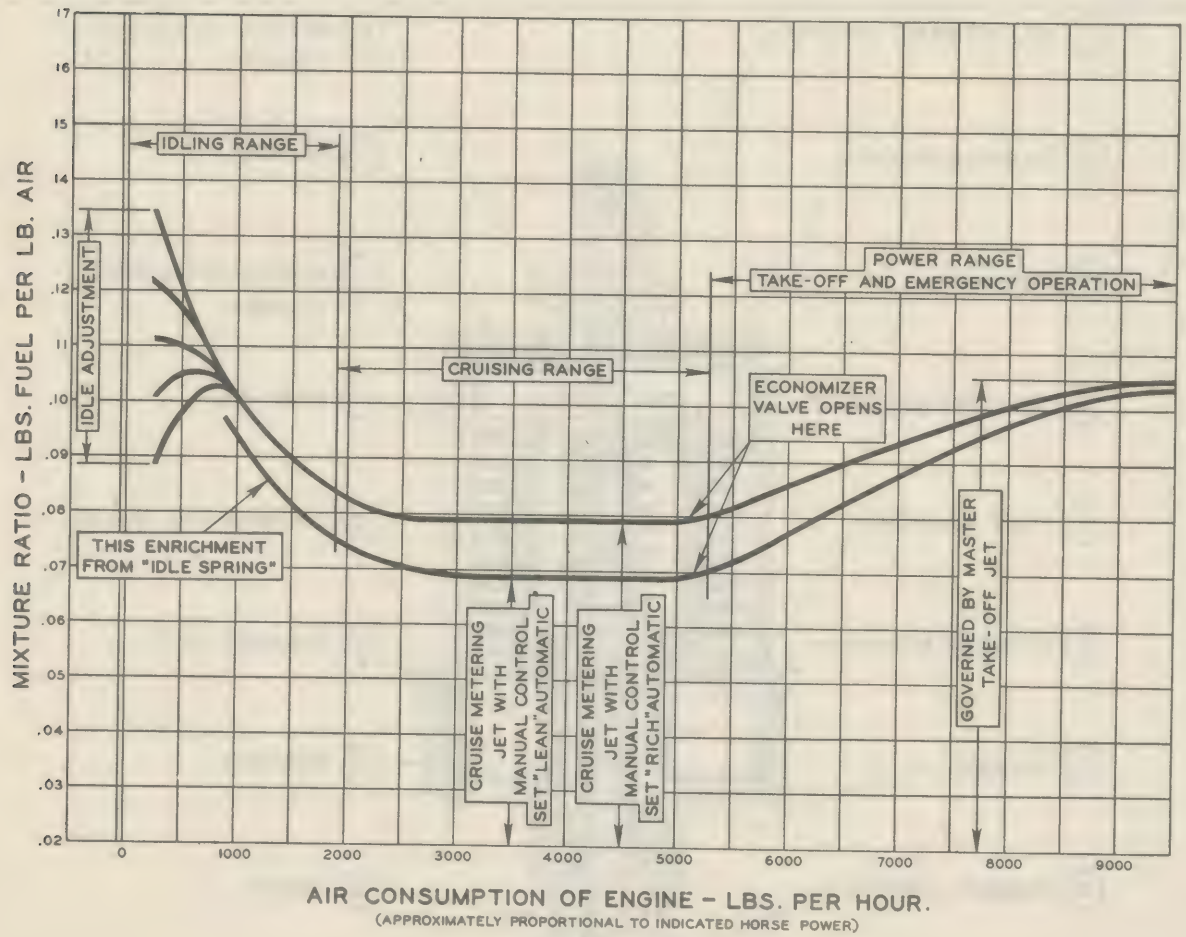


Fig. 88.

DIAGRAM OF INJECTION CARBURETOR ADAPTER
WITH SINGLE DIAPHRAGM
ACCELERATION PUMP AND SPRAY NOZZLE

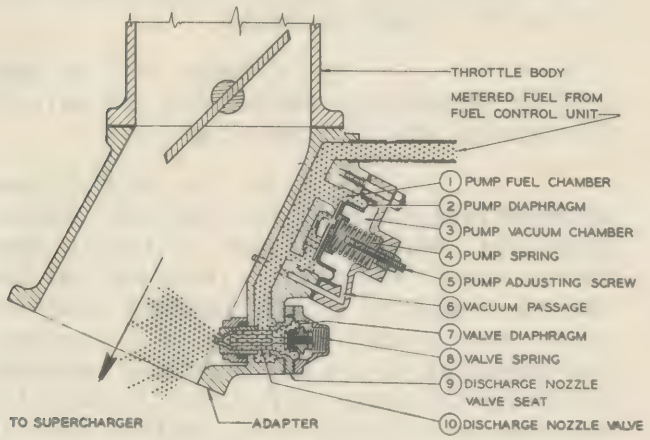


Fig. 89.

DIAGRAM OF INJECTION CARBURETOR ADAPTER
WITH DOUBLE DIAPHRAGM
ACCELERATION PUMP AND SPRAY NOZZLE

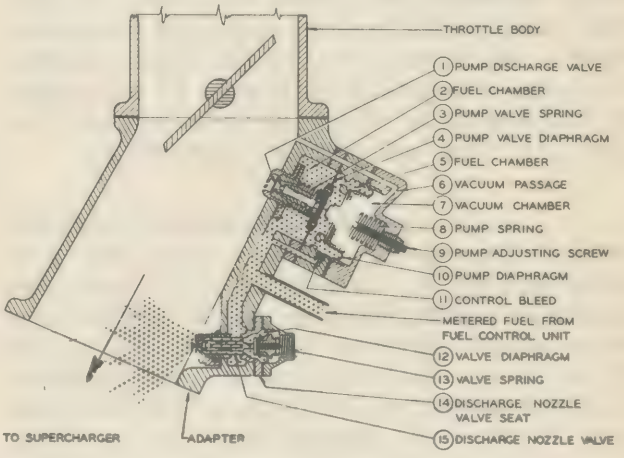


Fig. 90.

INSTALLATION DIAGRAM OF STROMBERG INJECTION CARBURETOR

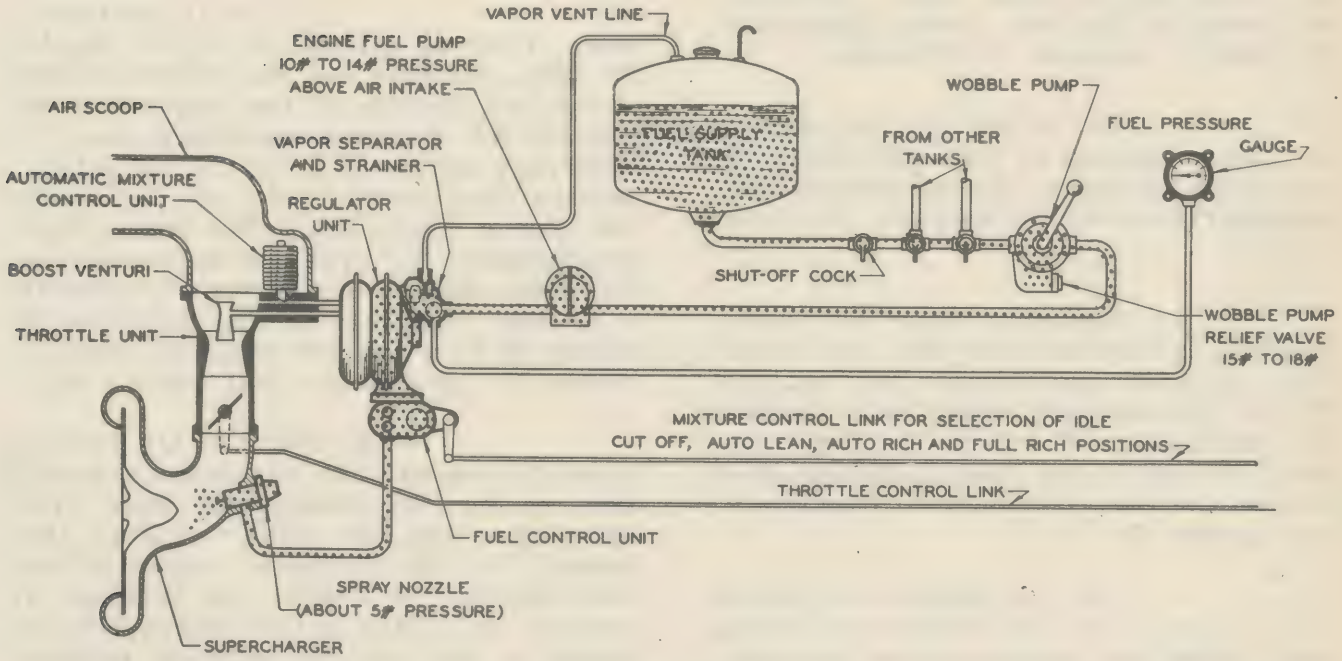


Fig. 91.

(f) Perhaps the most novel element of this new device is the simple means by which the flow of fuel to the Fuel Control Unit and the metering pressures across the fixed jets in the Fuel Control Unit are accurately regulated at all times by the Regulator Unit according to the mass air flow and venturi depression.

(g) The pressure difference between the venturi throat and the air scoop acting in the Air Section of the Regulator Unit produces an Air Metering Force which controls the Fuel Metering Force in the Fuel Section of the Regulator Unit. The metering pressure across the jets in the Fuel Control Unit is regulated by the Air Metering Force. Thus the flow through each jet in the Fuel Control Unit is substantially equal to that which would be obtained if the same size jet discharged into the venturi air passage from a float chamber vented to air scoop, as in previous suction type carburetors; and for constant air intake density, the same inherent uniformity of fuel-air ratio, independent of throttle position, is obtained.

(h) Correction for varying air intake density is then automatically made by the Automatic Mixture Control Unit. See description of Automatic Mixture Control.

(5) **Regulator Unit.**--The Regulator Unit is divided into two sections: (fig. 92) an Air Section and a Fuel Section. The Air Section is divided into Chamber "A" and Chamber "B" by the Air Diaphragm, equal in size to the Fuel Diaphragm which divides the Fuel Section into Chamber "C" and Chamber "D."

(a) ***Air Section of Regulator.***--Chamber "A" is connected to the impact tubes and registers scoop pressure. Chamber "B" is connected to the boost venturi and registers venturi suction. The pressure difference between the two chambers is a measure of air flow and when corrected by the Automatic Mixture Control is a measure of mass air flow. The pressure difference between Chamber "A" and "B" acting on the ***Air Diaphragm*** produces a force to the right, tending to open the fuel valve. This force is termed the ***Air Metering Force.***

(b) ***Fuel Section of Regulator.--1.*** Chamber "D" is connected to the fuel supply line, and the unmetered side of the Fuel Control Unit.

2. Chamber "C" is connected to the spray nozzles and the metered side of the Fuel Control Unit.

3. As the supply pump delivers fuel, Chamber "D," the Fuel Control Body, and Chamber "C" are filled successively. When fuel reaches the spray nozzles and the pressure at the nozzles rises to 5 lb. per square inch, or to a pressure corresponding to the nozzle spring setting, discharge begins. Any flow through the metering jets in the Fuel Control Body is accompanied by a decrease in pressure between Chambers "D" and "C" in the Regulator Unit. The pressure difference between Chambers "D" and "C" acting, on the ***Fuel Diaphragm*** produces a force to the left, tending to close the fuel valve. This force is termed the ***Fuel Metering Force.***

4. The ***Air Metering Force,*** from the Air Section of the Regulator Unit, controls the ***Fuel Metering Force*** in the Fuel Section of the Regulator Unit. When the ***Air Metering Force*** increases, the diaphragm assembly moves to the right, opening the Poppet Valve and increasing the flow of fuel through the Poppet Valve into Chamber "D." The increased supply of fuel into Chamber "D" raises the pressure in Chamber "D." This action increases the supply of fuel and the metering pressure across the jets in the Fuel Control Unit.

5. When the ***Air Metering Force*** decreases, the diaphragm assembly moves to the left closing the Poppet Valve and decreasing the supply of fuel into Chamber "D." The decreased supply of fuel into Chamber "D" lowers the pressure in Chamber "D." This action decreases the supply of fuel and the metering pressure across the jets in the Fuel Control Unit.

6. As an example, assume the "air metering force", resulting from air flow and venturi depression in the air section, transmitted to the Fuel Section, produces a metering pressure of 1/2 lb. per square inch on the fuel diaphragm. (Pressure in "D" will be 1/2 lb. per sq. inch higher than in "C.") The fuel flow quantity from the Fuel Control Unit will

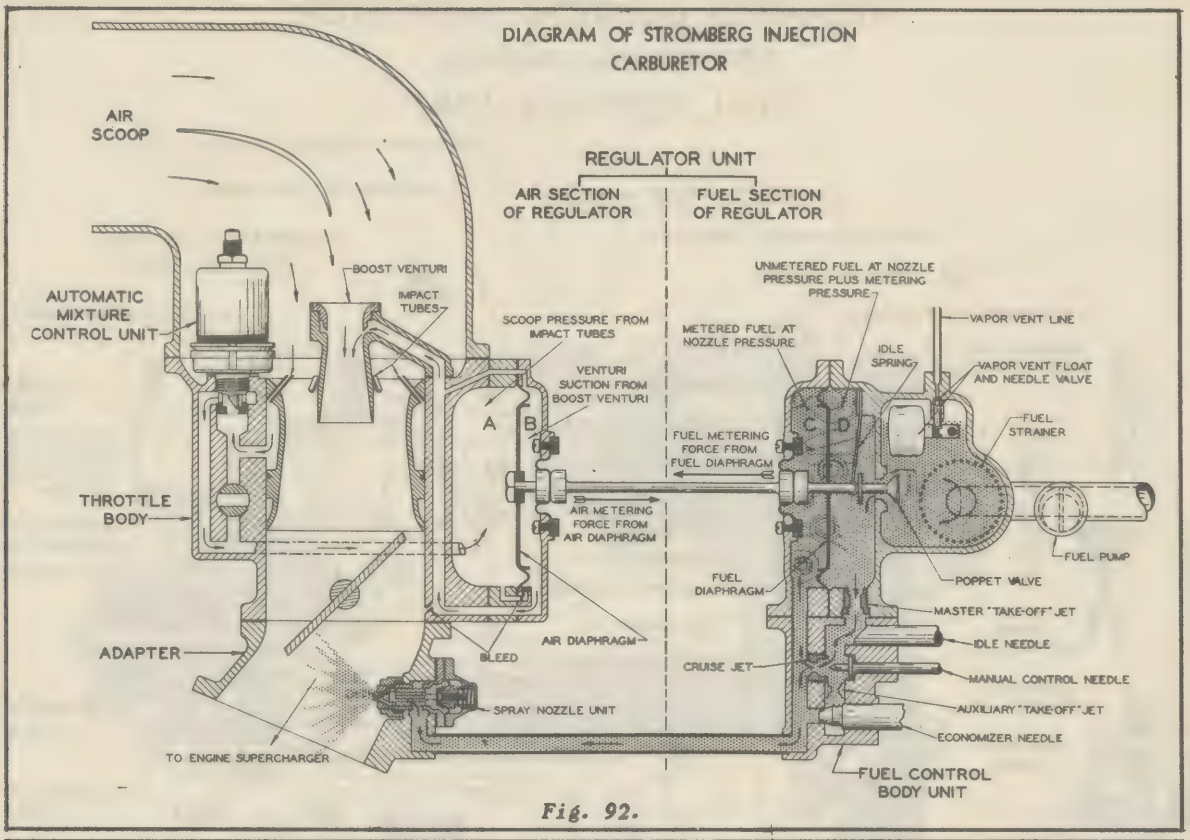


DIAGRAM OF STROMBERG INJECTION CARBURETOR
AIR SCOOP
REGULATOR UNIT
AIR SECTION OF REGULATOR
FUEL SECTION OF REGULATOR
AUTOMATIC MIXTURE CONTROL UNIT
BOOST VENTURI
IMPACT TUBES
SCOOP PRESSURE FROM IMPACT TUBES
VENTURI SUCTION FROM BOOST VENTURI
A
B
THROTTLE BODY
AIR METERING FORCE FROM AIR DIAPHRAGM
ADAPTER
AIR DIAPHRAGM
BLEED
SPRAY NOZZLE UNIT
TO ENGINE SUPERCHARGER
UNMETERED FUEL AT NOZZLE PRESSURE PLUS METERING PRESSURE
METERED FUEL AT NOZZLE PRESSURE
IDLE SPRING
VAPOR VENT LINE
VAPOR VENT FLOAT AND NEEDLE VALVE
FUEL STRAINER
C
D
FUEL METERING FORCE FROM FUEL DIAPHRAGM
FUEL PUMP
FUEL DIAPHRAGM
POPPET VALVE
MASTER "TAKE-OFF" JET
IDLE NEEDLE
CRUISE JET
MANUAL CONTROL NEEDLE
AUXILIARY "TAKE-OFF" JET
ECONOMIZER NEEDLE
FUEL CONTROL BODY UNIT

Fig. 92.

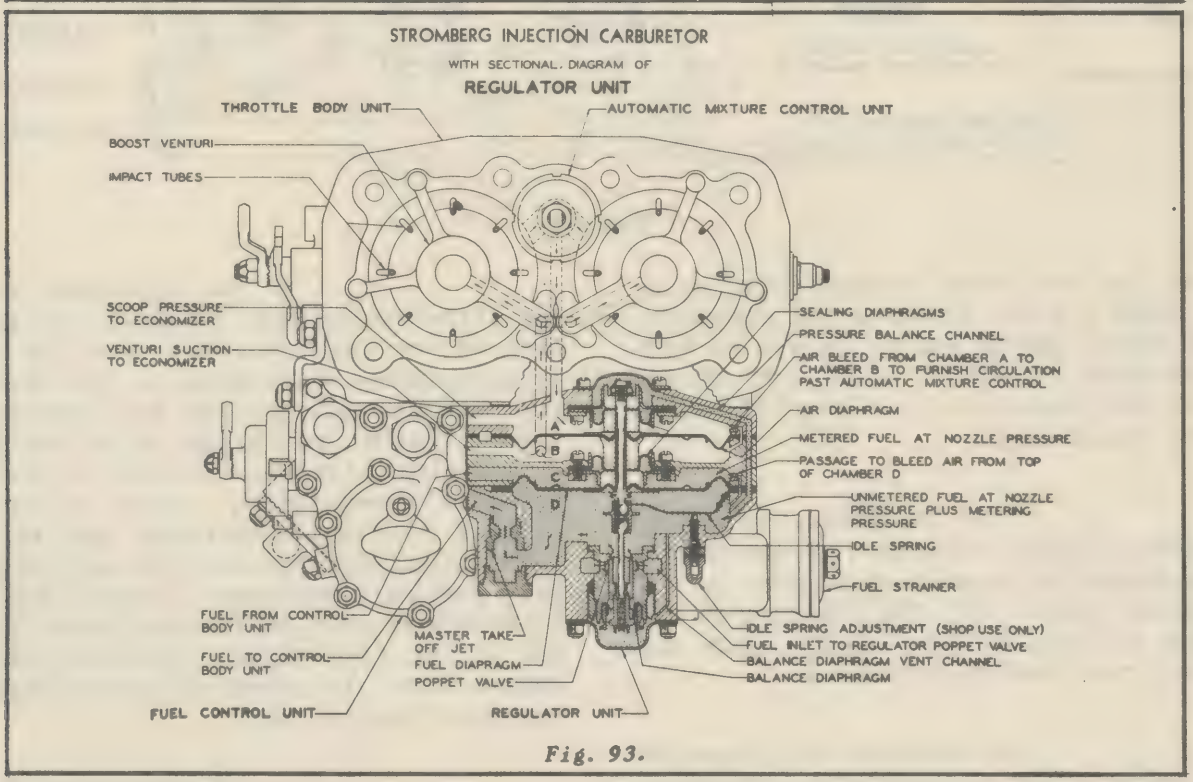

STROMBERG INJECTION CARBURETOR
WITH SECTIONAL DIAGRAM OF
REGULATOR UNIT
THROTTLE BODY UNIT
AUTOMATIC MIXTURE CONTROL UNIT
BOOST VENTURI
IMPACT TUBES
SCOOP PRESSURE TO ECONOMIZER
VENTURI SUCTION TO ECONOMIZER
SEALING DIAPHRAGMS
PRESSURE BALANCE CHANNEL
AIR BLEED FROM CHAMBER A TO CHAMBER B TO FURNISH CIRCULATION PAST AUTOMATIC MIXTURE CONTROL
AIR DIAPHRAGM
METERED FUEL AT NOZZLE PRESSURE
PASSAGE TO BLEED AIR FROM TOP OF CHAMBER D
UNMETERED FUEL AT NOZZLE PRESSURE PLUS METERING PRESSURE
IDLE SPRING
FUEL STRAINER
FUEL FROM CONTROL BODY UNIT
FUEL TO CONTROL BODY UNIT
MASTER TAKE-OFF JET
FUEL DIAPHRAGM
POPPET VALVE
FUEL CONTROL UNIT
REGULATOR UNIT
IDLE SPRING ADJUSTMENT (SHOP USE ONLY)
FUEL INLET TO REGULATOR POPPET VALVE
BALANCE DIAPHRAGM VENT CHANNEL
BALANCE DIAPHRAGM

Fig. 93.

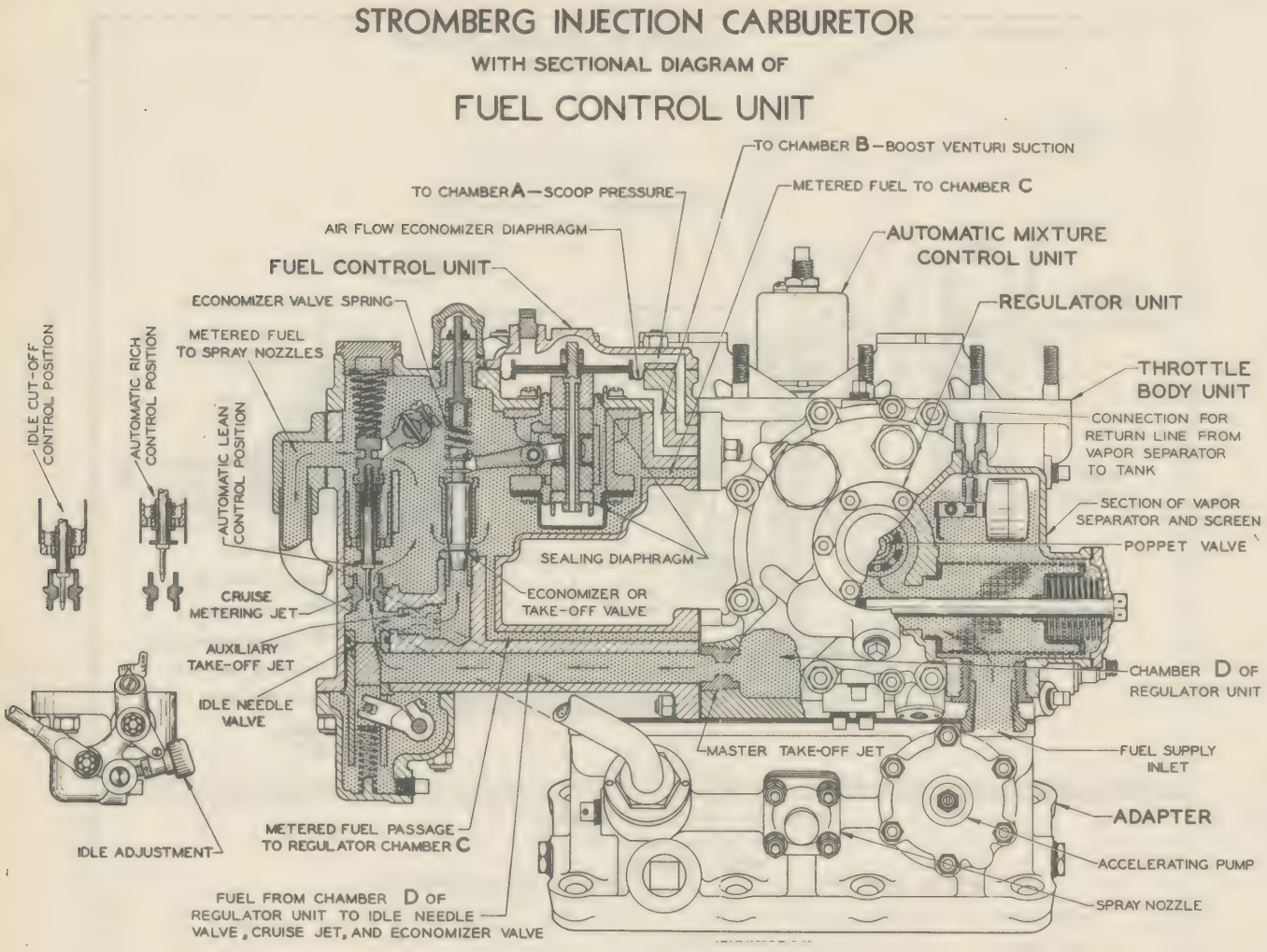

STROMBERG INJECTION CARBURETOR
WITH SECTIONAL DIAGRAM OF
FUEL CONTROL UNIT
TO CHAMBER B—BOOST VENTURI SUCTION
TO CHAMBER A—SCOOP PRESSURE
METERED FUEL TO CHAMBER C
AIR FLOW ECONOMIZER DIAPHRAGM
AUTOMATIC MIXTURE CONTROL UNIT
FUEL CONTROL UNIT
ECONOMIZER VALVE SPRING
REGULATOR UNIT
METERED FUEL TO SPRAY NOZZLES
THROTTLE BODY UNIT
IDLE CUT-OFF CONTROL POSITION
AUTOMATIC RICH CONTROL POSITION
AUTOMATIC LEAN CONTROL POSITION
CONNECTION FOR RETURN LINE FROM VAPOR SEPARATOR TO TANK
SECTION OF VAPOR SEPARATOR AND SCREEN
POPPET VALVE
SEALING DIAPHRAGM
CRUISE METERING JET
ECONOMIZER OR TAKE-OFF VALVE
AUXILIARY TAKE-OFF JET
CHAMBER D OF REGULATOR UNIT
IDLE NEEDLE VALVE
MASTER TAKE-OFF JET
FUEL SUPPLY INLET
ADAPTER
METERED FUEL PASSAGE TO REGULATOR CHAMBER C
IDLE ADJUSTMENT
ACCELERATING PUMP
FUEL FROM CHAMBER D OF REGULATOR UNIT TO IDLE NEEDLE VALVE, CRUISE JET, AND ECONOMIZER VALVE
SPRAY NOZZLE

Fig. 94.

then be that delivered through the metering jets under 1/2 lb. differential pressure. If the spray nozzle spring is set to hold the pressure in "C" to 5 lb. per square inch, the pressure in "D" will be 5½ lb. per square inch.

7. The flow rate is independent of nozzle pressure. If the nozzle spring should be increased to give 10 lb. per square inch in "C", the pressure in "D" will go to 10½ lb. per square inch and the fuel rate remain unchanged.

8. Metered fuel from the Fuel Control Unit is carried to the spray nozzle located in the engine casting at the supercharger entrance, or if not allowed for in the engine design, in an adapter casting located between the engine casting and the throttle body.

9. The sectioned part of the illustration fig. 93 shows the actual form of the Regulator Unit and its relationship to the other parts of the Carburetor. The Air Section and Fuel Section of the Regulator are assembled as one unit. In addition to the Fuel and Air diaphragms, previously mentioned, a pair of smaller opposed sealing diaphragms are used to avoid unbalance between the air and the fuel system pressures. A small balance diaphragm is also used on the Poppet Valve. All of the diaphragms, spacers, and the Poppet Valve are assembled on one stem and move as a single element.

10. The Regulator Unit is fastened to the Throttle Body, and to the Fuel Control Body. Passageways in the Throttle Body connect Chamber "A," past the Automatic Mixture Control Unit, to the impact tubes registering scoop pressure,

and Chamber "B" to the boost venturi registering venturi suction. Passage ways from the top of Chamber "A" and Chamber "B" carry scoop pressure and venturi suction through the top flange of the Regulator to the Air Flow Economizer located in the Fuel Control Unit. (See description of Economizer under Fuel Control Unit.) A fuel passageway from the top of Chamber "C" of the Regulator, is carried through the top flange to the metered side of the Fuel Control Unit to permit air or vapor in Chamber "C" to pass into the Control Unit, and to pass out of the Carburetor.

11. Fuel under pressure from the supply pump enters the Regulator Unit through the strainer and vapor separator fig. 94, passes through the Poppet Valve into Chamber "D" fig. 93 as unmetered fuel. The fuel flows out of Chamber "D" through a master take-off jet and passage in the bottom flange of the Regulator Unit to the metering jets in the Fuel Control Unit. A return passageway through the bottom flange permits metered fuel to fill Chamber "C" at metered pressure.

12. A small passageway with a control bleed connects the top of Chamber "D" to the top of Chamber "C." Air collecting in "D" passes through the bleed to "C" and is carried out of the Regulator with the metered fuel.

13. In addition to the "metering force" obtained from the Air Diaphragm an Idle Spring is employed to hold the Poppet Valve open when the engine is not running, and to give a slight enrichment to the mixture at very low airflows, at both full open and part throttle (see fig. 88). The spring is adjustable during assembly to add appredetermined force, usually about one inch gasoline head, to that derived from the Air Diaphragm.

14. This adjustment is for manufacturing and overhaul use only and should not be used after installation of the carburetor on the engine. An idling mixture ratio adjustment for use on the engine is provided on the Fuel Control Unit (see fig. 94).

(6) **Fuel Control Unit with Air-Flow Economizer.**--(a) Modern aircraft engines require large variations of fuel/air ratios at different operating conditions. Typical requirements are represented by the curves in fig. 88. In the idling range comparatively rich mixtures, capable of being adjusted, are required. In the cruising range a rich cruise or a lean cruising condition must be available. Gradually increasing richness from either cruise condition is required up to the maximum power operation.

(b) The Fuel Control Unit is designed so that metering jets and other variables may be selected to fit the mixture ratio requirements of the engine under all operating conditions.

(c) The sectioned part of the illustration fig. 94 shows one of the constructions employed.

(d) The variable parts controlling the mixture ratio in each range of engine operation are indicated on the curve sheet fig. 88 and the actual parts are shown in fig. 93 and fig. 94. An explanation of how these variables operate will indicate how the desired mixtured ratios are obtained for each condition of engine operation. Keep in mind the fact the Regulator Unit maintains the correct metering pressure, and supplies fuel, ready for metering, to the Fuel Control Unit at all parts of the curves.

(e) **Idling Range.--1.** In fig. 88 the Idling Range is from 0 to 1900 lb. of air per hour. The maximum richness which can be obtained in these limits is determined by the setting of the Idling Spring on the back of the Regulator. See Regulator illustration, fig. 93. At idling conditions the metering force derived from the Air Diaphragm in the Regulator Unit is not sufficient to open the Poppet Valve. The idle spring is used to hold the valve open for fuel flow and metering pressure at idling. The spring setting is made too rich for normal operation, the fuel flow then being cut down as desired by adjustment of the contoured idle needle valve in the Fuel Control Unit. This valve is connected by suitable linkage to the throttle valve so that it is completely opened at about 10-degrees of throttle opening. Refer to fig. 94.

2. Unmetered fuel flowing out of Chamber "D" through a master take-off jet in the bottom of the Regulator enters the Fuel Control Unit through the lower connecting flange and follows the passage way at the bottom of the Fuel Control Unit to the idle needle valve. Fuel is metered through the idle needle valve with a metering head equal to the pressure difference between Chambers "C" and "D" in the Regulator Unit. The metered fuel at idling volume passes through the cruise jet with no additional metering, rises to the top of the Fuel Control Unit and passes out through the fuel line to the spray nozzles. Different adjustments of the idle screw change the needle valve position throughout this low throttle range, to give the variation of idle mixture ratios shown on fig. 88 from 0 to 800 lb. air per hour.

(f) *Cruising Range.--1.* On fig. 88 the cruising range is from 1900 to 5300 lb. air per hour. After about 10° of throttle movement, the idle needle valve is drawn out to its open position. Fig. 94. The metering shifts from the orifice formed between the idle needle valve and seat, to the cruise jet when the area of the idling orifice is approximately equal to the area of the cruise jet. The mixture ratios from approximately 1900 to 5300 lb. of air per hour are therefore controlled by the cruise jet and the master take-off jet, if used. The auxiliary take-off jet has no effect on cruising range mixture ratios. The metering head is equal to the pressure difference between Chambers "C" and "D" in the regulator. The requirements are a choice of manual selection by the pilot between two predetermined limits, the richer one being the leanest fuel/air ratio that will be safe under all cruising conditions; the leaner one, the leanest mixture that is advantageous to use under the most favorable operating conditions.

2. Referring to fig. 94, the "Rich automatic cruise" mixture is determined by the unobstructed capacity of the cruise metering jet. "Lean automatic cruise" mixture is obtained when the manual control needle is lowered into the cruise jet orifice, thus reducing its effective area.

3. Typical fuel/air curve obtained with Injection Carburetor and Fuel Control Unit. Note that cruise and take-off values are maintained under altitude and temperature change, independently of propeller pitch, engine speed, or throttle position.

(g) *Power Range, Take-off and Emergency Operation.--1.* The Power Range as indicated in fig. 88 is from the upper limit of cruising 5300 to 9500 lb. of air per hour. Requirements are for gradually increasing fuel/air ratios from either rich or lean cruise position up to 9500 lb. of air per hour, or maximum air consumption.

2. This enrichment is obtained by an economizer valve operated by a diaphragm against a calibrated and preadjusted spring. The diaphragm is acted upon by the pressures in Regulator Chambers "A" and "B" of the Regulator Unit, which pressures are proportional to the mass air flow rate. The movement of the valve is therefore proportional to the mass air flow to the engine. This design is referred to as an air flow economizer. The rate of enrichment with increasing power is determined by the taper on the economizer needle and the economizer valve spring, while the upper limit of enrichment is determined by the size of the master take-off jet in the Regulator.

3. Unmetered fuel flowing from Chamber "D" of the Regulator Unit passes through the master take-off jet, past the idle needle valve which is drawn out of the passage, to the space in front of the cruise jet and the economizer valve.

4. As the economizer valve is opened, at the beginning of the power range, part of the fuel flows through the cruise jet and part through the economizer valve. Fuel is metered through the cruise jet, and the economizer valve, with a metering head equal to the pressure difference between Chambers "C" and "D" in the Regulator Unit. The metered fuel flows to the top of the Fuel Control Unit and passes out the line to the spray nozzles. As the mass air flow to the engine increases, the volume of fuel delivered to the Fuel Control Unit increases proportionally, the economizer valve also opens proportionally, giving the curves shown in the Power Range on fig. 88. When the areas

of the cruise and economizer orifices become approximately equivalent to the area of the orifice in the master take-off jet, the metering shifts to the master take-off jet.

5. The size of the master take-off jet determines the maximum enrichment.

6. Two locations for the take-off jet are shown. When the auxiliary take-off jet (dotted in illustration), fig. 94 is used, the master take-off jet may be omitted. In this case, the manual control will give a change of mixture ratio at both cruise and take-off power.

7. If it is desired to hold the take-off mixture ratio constant while the cruise ratio is varied, the auxiliary take-off jet is omitted and the master take-off jet employed. In this case, the cruise setting must be obtained by varying the cruise jet and master take-off jet in series, their mutual relation depending upon the amount of enrichment desired during take-off. For air-cooled engines they will need to be of nearly equal size.

(h) ***Idle Cut-off.--1.*** Idle cut-off stopping the engine is obtained by moving the manual mixture control to the extreme limit of its travel. This depresses the mixture control needle until a disc valve strikes the top of the cruise jet as shown in fig. 94 and cuts off all fuel flow except that through the very small orifice venting the top of Chamber "D" to "C" in the Regulator Unit, fig. 93. This flow is insufficient to run the engine.

2. Reviewing the operation of the Fuel Control Unit, the idling needle is operated by the throttle. A pilot's manual control lever is connected to give in one extreme position "Idle cut-off;" then in succession, a position for "Automatic Lean Cruise," a position for "Automatic Rich Cruise," and finally opening the Automatic Mixture Control by-pass valve, which will give a "Full Rich" setting.

3. It will be noted that except for the idle and by-pass valve, ***all operating manual mixture settings are automatically held uniform*** through changes of altitude and temperature, and ***that the desired fuel/air ratio is not disturbed by change of throttle position, engine speed, or propeller pitch.***

4. The design of the Fuel Control Unit is subject to wide modification. Any desired arrangement and selection of fuel metering orifices may be employed, according to the functions desired.

5. In working out a setting for the Injection Carburetor, referring to fig. 88, the maximum enrichment in the Idling Range is determined by the setting of the idle spring on the Regulator Unit. The range of idle curves can be varied by changing the size and shape of the idle needle and by adjusting the connection to the throttle which draws the idle needle out of the main fuel passage.

6. The fuel/air ratio in the cruising Range, with the Pilot's Manual Control set at "Automatic Rich Position," is determined by the unobstructed capacity of the cruise jet. "Automatic Lean Cruise" is obtained when the manual control lowers the lean cruise needle into the jet orifice, leaving a pre-determined area around it.

7. The Power Range is governed by the Economizer. The rate of enrichment with increasing power is determined by the taper on the economizer needle. The upper limit of enrichment is determined by size of the "Take-off Jet."

(7) **Adapter.**--(a) The spray nozzles are usually mounted to spray the fuel into the supercharger entrance. If not allowed for in the engine design, the nozzles can be mounted in an adapter casting placed between the supercharger and the carburetor.

(b) When an adapter is used a vacuum operated acceleration pump can be mounted on the adapter.

(c) Fig. 89 shows a diagram of an adapter with a spray nozzle, and Single Diaphragm Acceleration Pump, and fig. 90 an adapter with a spray nozzle and Double Diaphragm Acceleration Pump.

(d) Metered Fuel from the Fuel Control Unit enters the adapter and follows a passage to the spray nozzle and acceleration pump. When the pressure of the fuel on the nozzle diaphragm reaches 4 to 5 lbs. per square inch, or the pressure at which the nozzle spring is set to open, the force of the spring is overcome and the nozzle opens discharging fuel into the supercharger entrance. The nozzle will remain open permitting discharge as long as the pressure does not drop below 4 to 5 lbs. per square inch. The Single Diaphragm Acceleration Pump fig. 89 is automatically operated by vacuum. A passage (6) leads from below the throttle valve to the Pump Vacuum Chamber (3). When the throttle is closed reducing the pressure below the throttle, the pressure is reduced in the Pump Vacuum Chamber (3). The pressure difference between the Pump Fuel Chamber (1) and the Pump Vacuum Chamber (3) acting on the diaphragm (2) produces a force which moves the diaphragm "outward" on a suction stroke compressing the spring (4). Fuel is drawn from the nozzle passage through the pump passages, filling the Pump Fuel Chamber (1). When the throttle is opened the pressure is increased on the vacuum side of the diaphragm (2), in Pump Vacuum Chamber (3). The spring pushes the diaphragm (2) inward on a discharge stroke forcing the fuel through the pump passages into the nozzle passage, causing fuel to be discharged quickly through the spray nozzle.

(e) The Double Diaphragm Acceleration Pump fig. 42 is also automatically operated by vacuum but differs from the Single Diaphragm Pump by causing an accelerating discharge through a spring-operated Discharge Valve and a separate discharge nozzle arranged to spray the charge directly into the air stream to the supercharger entrance, as well as causing an accelerating discharge through the regular spray nozzles.

(f) Two diaphragms are required to produce the action described.

(g) Metered Fuel from the Fuel Control Unit enters the adapter and follows a passage past the spray nozzle to Fuel Chamber (2) of the Accelerating Pump. The Discharge Valve (1) is held shut by the spring (3) except during an accelerating discharge. A fuel passage leads from Fuel Chamber (2) through a Control Bleed (11) to Fuel Chamber (5) on the other side of Diaphragm (4); a Vacuum Passage (6) leads from below the throttles to Vacuum Chamber (7).

(h) When the throttles are closed reducing the pressure below the throttles, the pressure is reduced on the vacuum side of Diaphragm (10) in Vacuum Chamber (7). The pressure difference between the Fuel Chamber (5) and the Vacuum Chamber (7) acting on the Diaphragm (10) produces a force which moves the Diaphragm "outward" on a suction stroke compressing the Spring (8). Fuel is drawn from the nozzle passage through the Control Bleed (11) into Fuel Chamber (5). When the throttle is opened the pressure is increased suddenly on the vacuum side of the Diaphragm (10) in Vacuum Chamber (7). The Spring (8) pushes the Diaphragm (10), suddenly increasing the pressure on the fuel in the Fuel Chamber (5). The pressure in Chamber (5) produces a force on Diaphragm (4) which overcomes the Spring (3) opening the Discharge Valve (1). The pressure on the fuel in Chamber (2) increases suddenly causing an accelerating discharge through the Discharge Valve (1) directly into the air stream to the supercharger as well as an accelerated discharge through the regular nozzles, as the pressure rises in Fuel Chamber (2) is transmitted through the fuel passage way to the regular nozzles. The fuel is forced out of Fuel Chamber (5) at a controlled rate through the Control Bleed (11) into the passage to the discharge nozzles and Chamber (2).

(i) As the pressure in Fuel Chamber (5) drops, the Discharge Valve (1) closes and the Diaphragms (4 and 10) return to the discharged position ready for the next suction application.

(8) **Installation Requirements.**

(a) ***Engine Installation. 1.***--The engine installation requirements of the Injection Carburetor differ chiefly from those of previous carburetor models in requiring first, the fitting of spray nozzles directed toward the supercharger entrance, and second, the use of an engine fuel pump that will deliver fuel to the carburetor at 15 pounds pressure.

2. If the spray nozzles are not provided for in the engine design,

they may be mounted in an adapter casting located between the throttle unit and the engine flange. Best fuel economy will be obtained when the nozzles are arranged so the fuel spray fills the entire opening to the supercharger.

(b) *Scoop Design.*--Care should be taken to avoid localization of temperature or impact pressure around the Automatic Mixture Control and to avoid parts in the Scoop that will fit down too closely over the entrance to the small or boost venturi. The multiple impact tubes in the carburetor air entrance provide an average impact pressure of the air entering the carburetor. The pressure difference between the throat of the small venturi and the impact tubes is a measure of air flow and when corrected by the Automatic Mixture Control is a measure of mass air flow.

(c) *Air Heater.*--None required. No condition has developed in service to indicate the need for supplying hot air to the Scoop, though, as might be expected when ice is forming on the wings and propeller, it will also tend to form on the screen between scoop and throttle body, or on the inside of the air intake passage. Trouble from this condition may be eliminated by taking air from a properly installed duct directly forward and inside the engine cowling. This duct should be provided with a valve so that carburetor air may be taken from inside or outside the cowling.

(d) *Fuel System.--1.* The fuel system may be the same as in previous practice except for the slightly higher pressure range.

2. From the diagram it will be clear that with this system the fuel is *never* normally *sucked* into the air intake system. It can only be *pumped* in. It is vital that an accurate pressure gage be installed in clear view of the pilot since its reading is an indication as to whether or not fuel is feeding through the spray nozzles. The engine fuel pumps must be of adequate capacity at both low and high engine speeds. The wobble pump should be capable of developing at least 12 pounds pressure, and its relief valve should be set so the line pressure cannot exceed 15 to 18 lb. sq. in.

(e) *Vapor Vent Line.--1.* A Vapor Separator, originally developed for conventional float type carburetor systems, has been incorporated in the design. This consists of a small vent valve in the top of the strainer chamber, held shut by a float, normally submerged in liquid fuel, which drops to open the vent when vapor enters the strainer chamber. A small vent orifice has been found to be adequate under ordinary service conditions. The vent system is particularly helpful in quickly re-establishing a new flow of fuel when the fuel lines and pumps have run dry due to emptying one tank.

2. The operation of the vent valve may be accompanied by a slight delivery of fuel, about two quarts per hour with an engine developing 1000 hp. It is, therefore, recommended that a small (¼") return line be run from the vent valve to the service tank as shown in fig. 91.

3. It is further recommended that precautions be taken to prevent the temperature of the fuel in the supply line to the carburetor, and in the Regulator Unit itself, from rising above 160° F. since aviation fuel may liberate quite large volumes of vapor just above this temperature limit even under the pressure used in this system.

4. Following is a rough approximation of the temperatures of rapid boiling in any fuel line, carburetor, or jet, assuming the tank in pressure equilibrium with the atmosphere at any altitude:

At tank pressure	130° F.
5 lb. above tank pressure	160° F.
10 lb. above tank pressure	190° F.
5 lb. below tank pressure	100° F.

(f) *Non-return Valves.*--A fuel system having any of the supply tanks located below the carburetor should always have a non-return valve in the fuel line ahead of the strainer to prevent fuel from draining back into the tank, and leaving the upper half of the Regulator and Control Units full of air, when the plane is left standing with engine stopped and fuel cocks open.

(9) **Maintenance Instructions for Injection Carburetors.**--In general there is

little attention required between carburetor overhauls; however, it is recommended that the items below be checked at regular periodic inspections.

(a) Check tightness and safetying of all nuts, bolts, and studs fastening carburetor to engine.

(b) Check all fuel line, and gage connections for leakage.

(c) Check all throttle, and mixture control rods, and levers for tightness and safetying.

(d) Oil and adjust manual control latch plates on Fuel Control Unit to allow free movement and definite position feel.

(e) Check idle adjustment, lock nuts, screws, and pins.

(f) Drain Regulator Unit air chambers and fuel chambers, and Fuel Control Unit through plugs in bottom.

(g) Remove and clean fuel strainer in Regulator Body.

(NOTE: Fuel Supply Line does not have to be disconnected to clean strainer.)

(h) WARNING: Do not flush Injection Carburetor with Carbon tetrachloride. To prevent damage to the diaphragms, use clean gasoline and new S. A. E. No. 10 Paraffin Base (Pennsylvania Crude) Motor Oil for cleaning and flushing.

3. INDUCTION SYSTEM.--*a. Supercharger.*--(1) **Definition.**--(a) Supercharging is a method by which a reduction of power with altitude can be largely offset. This is accomplished by an apparatus known as a supercharger. The supercharger is an air-pump driven by the engine, the purpose of which is to compress air to sea-level density and deliver it to the engine.

(b) The subject of supercharging is based on a study of mass, volume, and density as applied to the properties of gases. Like liquids and solids, gases have weight; but unlike liquids and solids, their weight is not of constant value under all conditions. For example, at sea-level pressure it requires approximately 13 cubic feet of air to weigh 1 pound, but at a higher pressure the same volume will be considerably heavier. For practical purposes, mass may be considered as identical with weight, or in other words a measure of true quantity. Mass is not to be confused with volume, since volume merely designates the space occupied and does not consider pressure or density. The relation between these factors is explained in certain laws pertaining to the behavior of gases. At constant temperature, the relation between volume and pressure can be best shown by a study of a definite quantity of air in a closed cylinder fitted with a movable piston (fig. 95).

(c) Assuming constant temperature and no leakage past the piston, it is apparent that volume and pressure are inversely related (Boyle's Law). The mass or quantity of air below the piston is the same in all cases, but as the volume is changed, the pressure will be affected. Density, or the mass for a given unit of volume, is also explained by a consideration of these properties. In fig. 95-1, if the density of the air is taken as standard, the air in 95-2, will have a density of 2, and the air in 95-3, will have a density of only ½. These facts have an important bearing on the performance of an internal-combustion engine, as the power developed depends principally upon the mass of induced charge. A nonsupercharged engine is able to induce only a definite volume according to its piston displacement and volumetric efficiency; therefore, in order to increase this mass of charge, it is necessary to increase the pressure and density of the incoming charge by the use of a supercharger. Therefore, the function of a supercharger is to increase the quantity of air (or mixture) entering the engine cylinders.

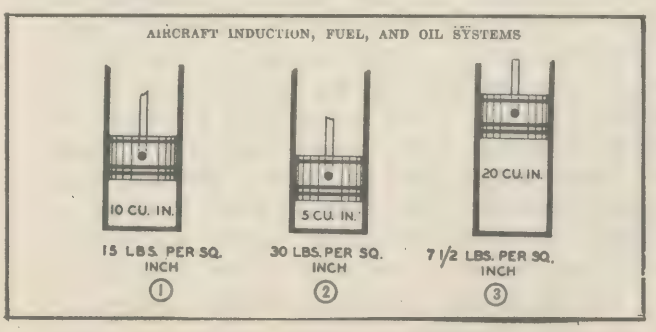


Fig. 95. Relative Volumes and Pressures.

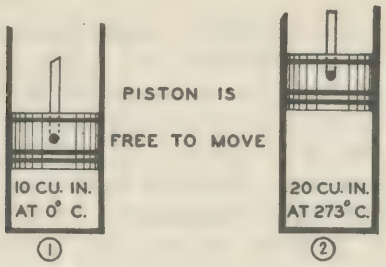


Fig. 96. Effect of Temperature on Gas Volumes.

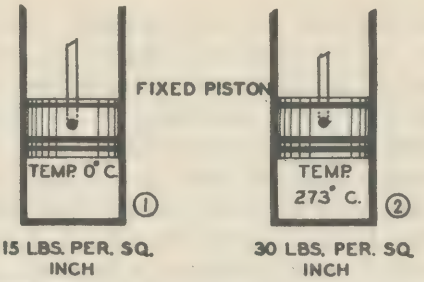


Fig. 97. Effect of Temperature on Gas Pressure.

(d) The elastic property of gases is also observed when temperature changes occur. If a given quantity of any gas is heated 1° C. the gas will, if not confined, expand 1/273 of its former volume (Gay-Lussac's law). If heated 273° C. under the same condition, the gas will expand 273/273 or will simply double its former volume, and the density will be reduced to one-half the original value (fig. 96).

(e) If a gas is confined so that free expansion cannot occur, an increase in temperature will result in an increased pressure (fig. 97). The relation between temperature and density must be considered in the operation of internal-combustion engines in order to insure the maximum power output.

(f) The weight of the earth's atmosphere is sufficient to exert considerable pressure on objects at sea level. At altitudes above sea level the pressures will not only be lowered, but the density of the air will also be reduced. At an altitude of 20,000 feet the pressure and density of the atmosphere are only one-half of the sea level value. Superchargers were originally developed to increase the density of the air taken into the cylinders at high altitudes so that full power output could be realized, and many superchargers are still employed for this purpose. However, with improved engines and better fuels, it is also very profitable to utilize a supercharger at low altitudes to increase the induction system pressure (and charge density) far above the normal atmospheric value. At one time, superchargers were considered merely an engine accessory, but they are now a vital part of every high-output engine.

b. Types of Superchargers.--(1) Although many types of superchargers have been designed, those illustrated in figs. 98, 99, and 100 give best results on modern engines.

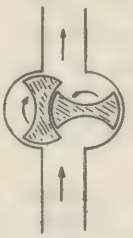


Fig. 98. Roots Supercharger.

(2) **The Roots Type Supercharger** (fig. 98), is generally mechanically driven from the engine crankshaft at a moderate speed. It is fairly efficient but is usually somewhat heavier than other types of equal output and may offer some problems in lubrication. However, the Roots type may be used with good results on certain engines. The sliding vane type supercharger (fig. 99) is also satisfactory but appears to be less desirable in most cases than the centrifugal type (fig. 100).

Fig. 99. Vane Supercharger.

(3) **The Centrifugal Type Supercharger** is remarkably efficient for aircraft engines, as it is simple, has few parts, and can be driven at rotative speeds far higher than would be permitted with other types. It is interesting to note that the centrifugal unit was first installed in order to overcome difficulties in charge

Fig. 100. Centrifugal Supercharger.

distribution and not to increase the charge density. As better aircraft fuels were developed, the natural procedure was to increase the gear ratios to obtain much higher manifold pressures. This higher supercharger output may be utilized either in producing a greater power for take-off or in obtaining a higher altitude rating. Centrifugal superchargers may be driven either through a gear train or by an exhaust gas turbine as described in subsequent paragraphs.

(4) In addition to their construction features, superchargers are also classified according to their location in the carburetion system. An impeller located in the induction system between the carburetor and engine cylinders is known as an internal supercharger, and when it is located on the air inlet side of the carburetor, it is classified as an external supercharger.

(5) **Internal Supercharger.**--The Internal Supercharger is composed of a centrifugal impeller, impeller drive, diffuser, and distribution chamber. The impeller vanes are curved in the direction of rotation. The impeller is driven through gearing from the crankshaft; this ratio is called the blower ratio. The diffuser is made up of annular vanes in the case surrounding the impeller through which the mixture is discharged under pressure into the distribution chamber. The distribution chamber is an annular passage inside the rear blower section or main section. The intake pipes are attached to this section by openings tangential to the case.

(6) **Two-speed Supercharger.**--The two-speed supercharger is a supercharger with two ratios which can be selected manually. It is operated by a hydro-valve. This valve controls the pressure of oil that is placed on either side of the clutch moving planetary gears in or out, thereby giving a high blower ratio or a low blower ratio. As the critical altitude is approached while operating in the low ratio, the manifold pressure will drop off gradually. The pilot will change the supercharger ratio going from low thru neutral to high while at the same time opening the throttle. This is done in such a manner to avoid rough operations and strains on the supercharging driving.

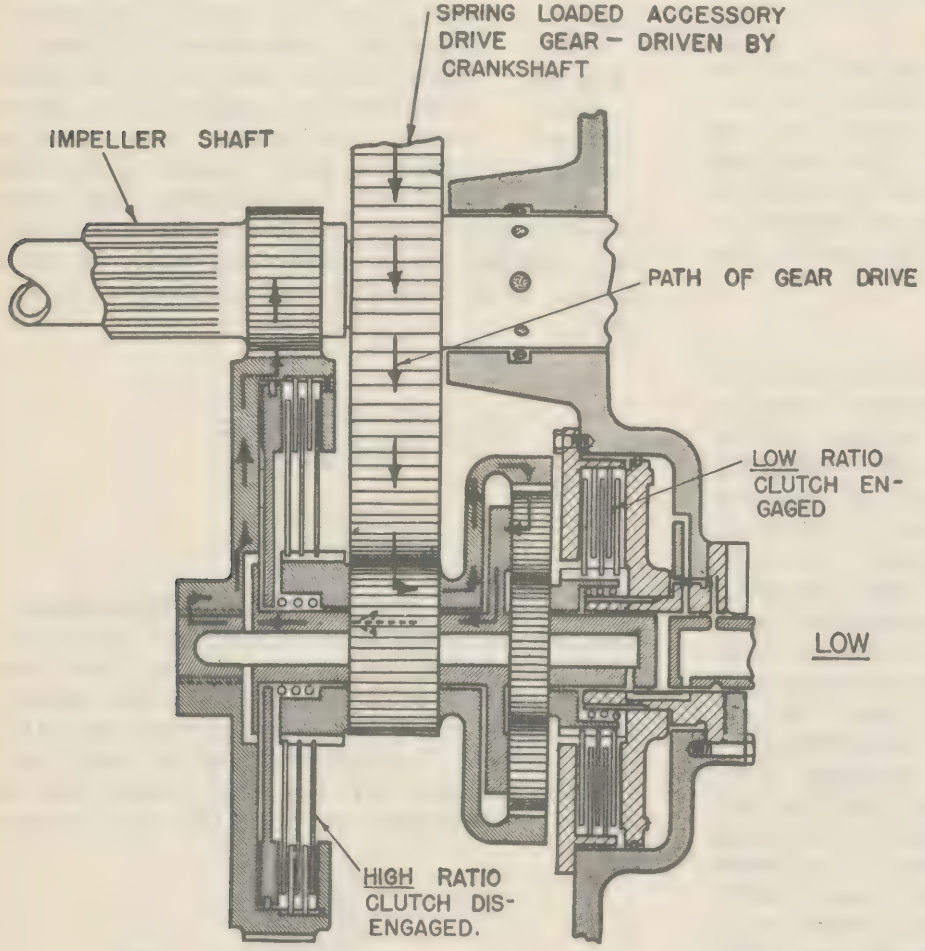

SPRING LOADED ACCESSORY DRIVE GEAR - DRIVEN BY CRANKSHAFT
IMPELLER SHAFT
PATH OF GEAR DRIVE
LOW RATIO CLUTCH ENGAGED
LOW
HIGH RATIO CLUTCH DISENGAGED.

Fig. 101. Internal Gear-Driven Supercharger Two-Speed in Low Ratio.

(7) **The Exhaust Turbine Supercharger.** The turbine supercharger is a type of controllable speed centrifugal compressor which derives its power from exhaust gases of the engine. The engine exhaust gas is completely enclosed in the exhaust manifold which conducts the gas to a nozzle box, where the gases are directed against buckets on the turbine wheel.

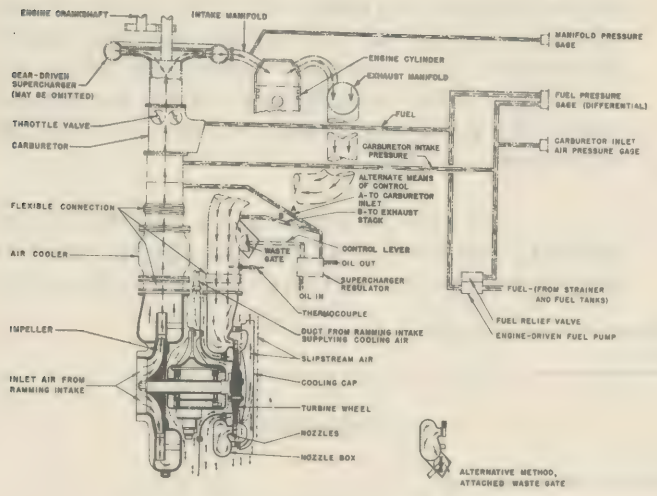


Fig. 102. Connection Diagram of Turbosupercharger System.

(8) The impeller on the centrifugal compressor is on the same shaft as the turbine wheel. The only major moving part in the supercharger is this shaft carrying the turbine and impeller wheels. This unit, which is supported on antifriction bearings, is called the "rotor." The speed of the rotor is controlled by one or more waste-gates in the exhaust system. By closing the gage (or gates) all of the exhaust gases can be directed against the buckets of the turbine wheel, or some may be allowed to escape into atmosphere by partially opening the gate. By this means the speed of the impeller can be varied in very small increments, so that the amount of supercharging at any altitude may be limited to the amount needed.

c. Advantages of Exhaust-driven Superchargers.--(1) The advantage of an exhaust-driven external supercharger over a mechanically-driven external supercharger for installation on the air inlet side of the carburetor is the comparative low power required for its operation at the higher altitudes. The power required to drive a gear-driven supercharger remains constant, but the power to drive an exhaust supercharger decreases with altitude. By referring to fig. 103 it will be noted that the turbine wheel which drives the supercharger impeller is driven by the pressure of the exhaust gases expelled from the engine cylinders. Assuming that the exhaust waste gate is closed and the engine is operating at a given speed, the speed of the turbine wheel is determined by the rate of flow of the exhaust gases through the nozzle box. As the atmospheric pressure decreases with altitude, it becomes evident that the exhaust gases will flow through the turbine wheel more freely, resulting in higher supercharger efficiency. In general practice the waste gate is open at low altitudes and closed at high altitudes. An intercooler of proper capacity is installed on the outlet side of the supercharger to reduce supercharged air temperature.

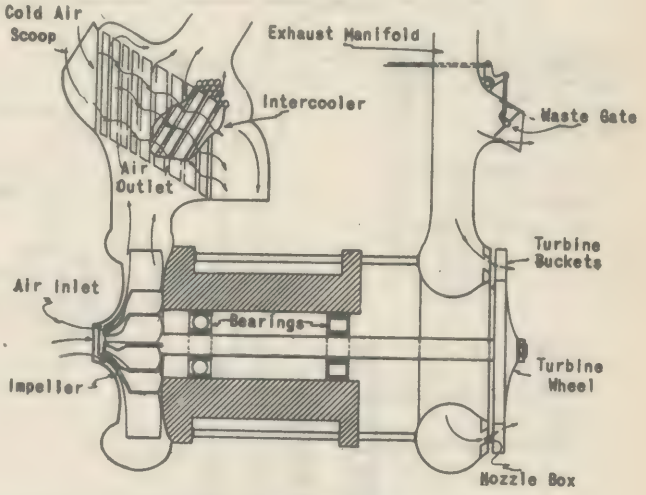


Fig. 103. Turbine Supercharger.

(2) Many airplane installations include both a gear-driven internal supercharger and an external turbo supercharger, which give two stages of pressure rise in the induction system *(fig. 104)*. This combination develops adequate induction pressures at high altitudes for unusually good airplane performance. An intercooler between the two impellers provides the necessary drop in air temperature to prevent overheating and detonation.

d. Supercharger Control.--(1) A supercharger of high capacity must be provided with some means of control in order to permit correct manifold pressure at all altitudes. In the case of the turbine-driven type this can be readily accomplished by providing a controlled escape for a certain portion of the exhaust gases. This method of control is quite satisfactory, since the supercharger output can be readily controlled to meet all operating conditions. Generally the waste gate will not be completely closed except when operating at a very high altitude. The control of the geared centrifugal supercharger is somewhat more difficult since its output is

determined principally by the speed at which it is driven.

(2) A common method of limiting the output of a gear-driven supercharger is to employ a throttle valve in the inlet passage to the supercharger, the carburetor throttles being ordinarily used for this purpose. At low altitudes the throttles must be only partially opened on highly supercharged engines, but as the altitude is increased, the throttles may be opened to obtain the correct manifold pressure reading. This arrangement will generally give the greatest power at one particular altitude.

(3) To eliminate the need for manual control, superchargers may be equipped with automatic regulators.

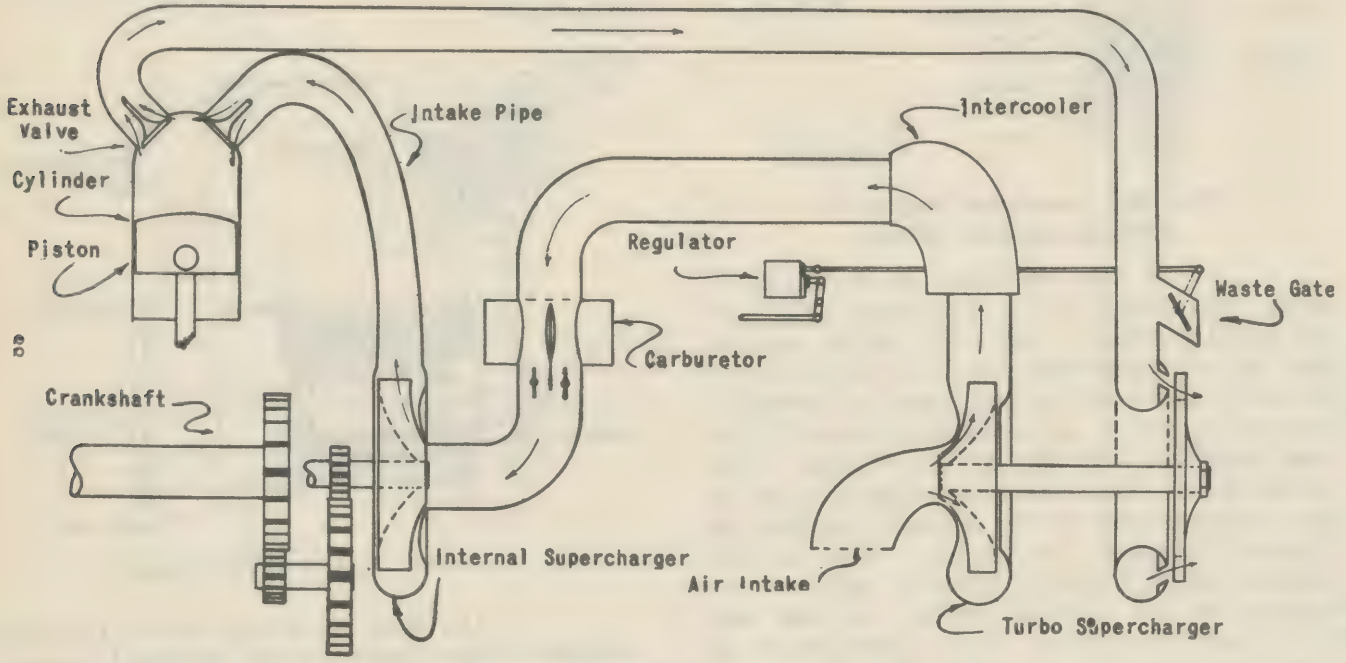


Fig. 104. Two-Stage Supercharger System

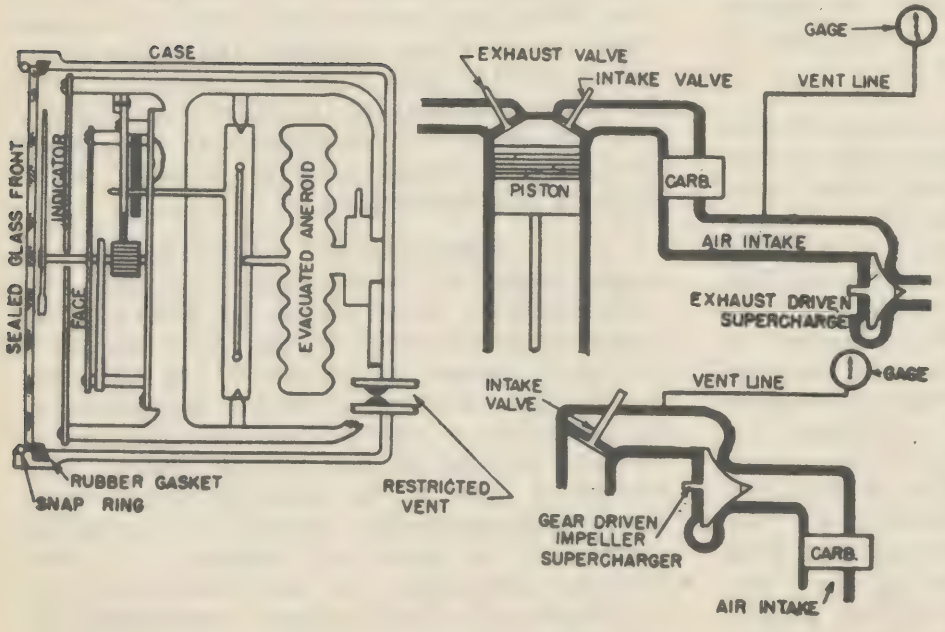


Fig. 105. Manifold Pressure Gage and Location.

Such regulators are sensitive to the developed manifold pressure and will adjust the throttle or waste gage control so as to maintain the correct pressure at all times. The control may be set either to maintain a standard reading at all altitudes or to limit the maximum pressure for take-off. Automatic regulation not only relieves the engine operator of serious responsibility but will also protect the engine from excessive stresses and detonation. A typical example of automatic supercharger regulator installation is shown in fig. 105.

e. Supercharger Regulator.--The supercharger pressure regulator, which operates the waste gate automatically, is a barometric device in conjunction with an oil operated serve piston, usually deriving its operating power from the oil pressure of the engine but in other cases from some other high pressure hydraulic system. It is controlled by the pressure preceding the carburetor in the constant pressure regulator and by the exhaust gas pressure in regulators equipped with a range shifter mechanism. It is regulated by the pilot by means of the supercharger control which serves primarily to turn the supercharger on or off. It is not entirely satisfactory for controlling manifold pressures except in a restricted range. Later models afford a wide range of manifold pressure regulation by the pilot.

4. FUEL SYSTEMS.--*a. General.*--(1) ***A well-designed fuel system must provide for the storage of the required amount of fuel in the available space within the airplane structure, and for the delivery of the fuel to the carburetor at the proper rate of pressure.*** The system must be positive and reliable under all conditions of flight and, if possible, simple in operation. Indicators, such as the fuel-pressure gage and tank-contents gages, are installed to give a continuous indication of the functioning of the system.

(2) The continued development of military airplanes has been accompanied by many new problems relative to fuel systems. The practice of installing numerous small tanks rather than a few larger ones has resulted in increasing plumbing and complication, but has also permitted a more efficient use of the available fuel storage space. The use of external superchargers also increases the demands on the fuel system, especially in regard to pump capacity at high altitudes. The trend of late developments in carburetors is also toward increased pressures for the delivery and discharge of the fuel. It is obvious that the fuel system of a modern airplane is a very complicated arrangement requiring careful installation, adjustment, and inspection.

b. Basic Fuel-System Circuits.--(1) Since each particular fuel system has certain special features, it is necessary to begin the discussion by considering first the simpler designs.

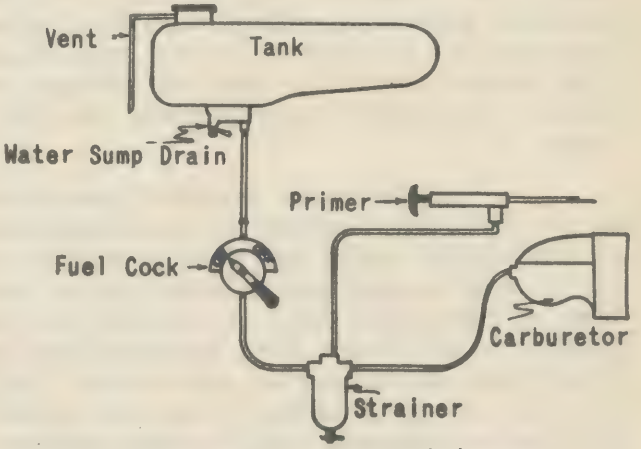


Fig. 106. Gravity Fuel-Feed System.

(2) **The Gravity Fuel System** (fig. 106), though elementary in design, is still in use on a number of training-type airplanes. The advantages are simplicity and reliability, but this system cannot be used on tactical airplanes because of structural arrangement and higher pressure requirements. The actual pressure available from a gravity system can be calculated as approximately 1 lb. per square inch for each 40 inches head of fuel. Thus, it may be estimated that in order to produce a delivery pressure of 3 lb. per square inch, a vertical head of 120 inches of fuel is necessary.

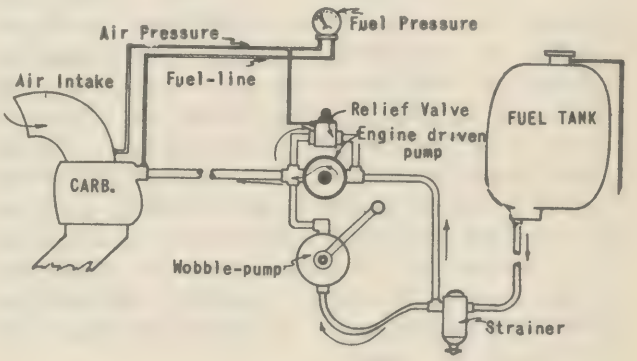


Fig. 107. Pressure Fuel-Feed System.

(3) Fig. 107 is a schematic diagram of a complete **Pressure Fuel System** of a relatively simple type. Certain additional units have been intentionally omitted in order that the basic principles can be more clearly indicated. In tracing the fuel flow, attention is called to the location of the main fuel strainer and the

arrangement of the two fuel pumps with a single relief valve. The use of an air vent line from the air intake to the pressure gage and relief valve is also significant. The direction of fuel flow from supply tanks to the carburetor is clearly indicated by arrows near the fuel lines.

(4) The exact pressure generated by the fuel pump depends on the adjustment of the relief valve and may be from 3 to 15 lb. per square inch according to the type of carburetor used on the engine. In general, the proper fuel pressure for a float-type carburetor or mechanical fuel injector is approximately 3 lb. per square inch; for a diaphragm type variable venturi carburetor, 5 to 6 lb.; and for a pressure injection carburetor, 13 to 15 lb. In all cases, these figures represent desired differential fuel pressure, and the pressure gage is connected so as to indicate this difference. In many airplanes the carburetor air pressure is appreciably higher than the normal atmospheric pressure, the increase being delivered by a ramming air intake or by an external supercharger.

c. *Fuel-System Units.*--(1) In order to clarify the principles of operation of complex airplane fuel systems, the various units are discussed separately in the following paragraphs:

(2) *Tanks.*--(a) Fuel tanks are usually constructed of aluminum, aluminum alloy, or stainless steel. The general design is indicated in fig. 108, but the shape is variable, depending on the airplane for which it is designed. Large tanks require internal baffles for increased rigidity and to prevent objectional surging of the fuel in flight. In order to counteract corrosion in aluminum and aluminum alloy tanks, a small capsule containing potassium dichromate is installed near the bottom of the tank.

(b) The filler necks of fuel tanks are so installed that an expansion space is automatically provided when the tank is serviced. A vent line from the top of the tank leads overboard so as to reduce the danger of fire from fuel or vapors which may be discharged. It is highly important that this vent line be properly installed and free from any obstruction.

(c) Most fuel systems provide a reserve fuel supply, either by the use of a separate reserve tank or by the arrangement shown in fig. 108. In either case, the reserve fuel supply is adequate to operate the engine for at least 20 minutes at full rated power.

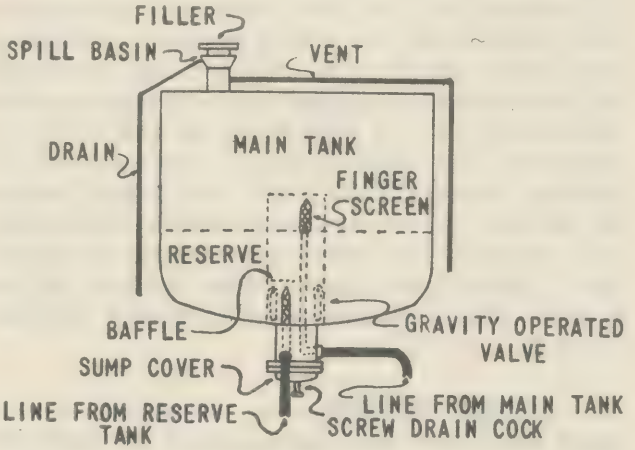


Fig. 108. Sectional View of Fuel Tank.

(d) Some airplanes, especially long-range types, may be equipped with special fuel tanks in order to increase the cruising range for a particular mission. When such tanks are serviced, attention must be given to the total weight of the airplane in order to prevent overloading.

(e) Water may be occasionally found in fuel tanks, either as a result of condensation or careless servicing; therefore, regular drainage of the tank sumps is most important.

(3) **Lines and Fittings.**-- (a) Fuel lines are generally made from copper or annealed aluminum alloy tubing, the latter being more common on late-model airplanes. The tubing size is governed by the fuel-flow requirements of the engine. Except for the lines between flexible connections, tubing should be properly supported by clamping it to structural members. A band of red paint near each end serves to identify a fuel line. Connections between tubing and fuel-system units are made by means of pipe fittings, solderless flared tube fittings, hose connections, or by a combination of these methods.

(b) Standard pipe thread fittings are shown in fig. 109. It will be noted that all threads on these fittings

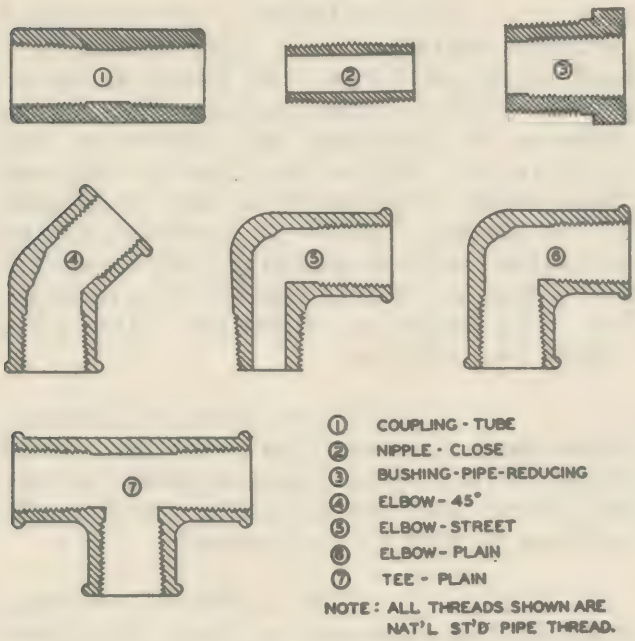


Fig. 109. Common Pipe Fittings Used in Airplane Plumbing.

are tapered ($\frac{3}{4}$ inch per foot), and therefore when screwed together make a leakproof connection by the sealing action of the threads. In installing these fittings, no attempt should be made to turn them until the threads are completely engaged. Permanent joint compounds are not required and are generally forbidden. Approved lubricants which do not harden will, however, be found beneficial in making pipe connections. It must be understood that these materials function purely as lubricants and not as sealing compounds for improperly installed fittings. Many fuel-system units, such as fuel tanks, fuel cocks, strainer, pumps, and carburetors, are provided with female pipe threads for the installation of various line fittings.

(c) For connecting thin-walled tubing to pipe fittings, the three-piece solderless fittings (fig. 110) are commonly employed. To make this type of connection, the tube is cut to proper length and a nut and sleeve are placed over the tube. The tube is then flared at the open end by an appropriate tool, and the nut is screwed on a nipple, elbow or similar fitting. In this case it must be noted that the seal is between the tube and fitting, at the flare, not in the threads. A small amount of lubricant on the threads will facilitate tightening, but the use of heavy sealing compound is unnecessary and possibly dangerous.

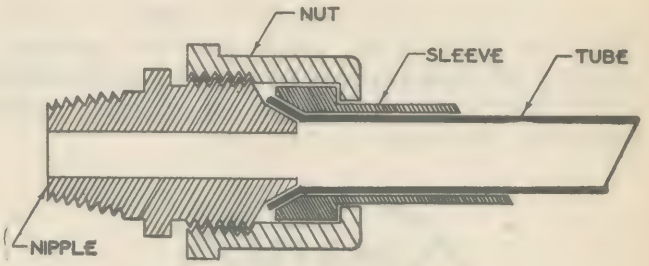


Fig. 110. Flared-Tube Union.

(d) Flexible hose connections are required between members where an appreciable amount of relative motion exists, such as between the engine and engine mount. A hose connection is installed on both ends of the connecting tube.

(e) Cone union fittings which are attached to copper tubing by high melting point solder may be used in fuel systems, but the solderless type is generally preferable.

(4) **Cocks and Dials.**--(a) Fuel cocks have a number of uses in airplane fuel systems. They perform such functions as tank selectors, engine selectors, cross feed valves, etc. The size and number of ports of fuel cocks naturally vary according to the type of installation for which they are intended. Fuel cocks must have the fuel flow capacity of the fuel lines, must be free from leakage, and at the same time operate with little effort. These requirements have produced considerable development on these units, with the result that satisfactory designs are now available.

(b) Fuel cocks having a cone-shaped cock rotor have been used quite extensively in fuel systems and have been fairly satisfactory. The principal disadvantage of this type is the high torque required for operation, resulting in a rather uncertain feel of the operating control. An improved model uses a cam arrangement for unseating the cone between index positions, thus improving the action. External clearance adjustments are provided on this type which must be maintained within proper limits.

(c) A metal cock with synthetic rubber inserts around the ports is also available. This type is simple, operates freely, and provides good sealing properties.

(d) The dial used in conjection with fuel cock has the proper number of positions for the particular installations. A diagram of a fuel cock and dial is shown in fig. 111.

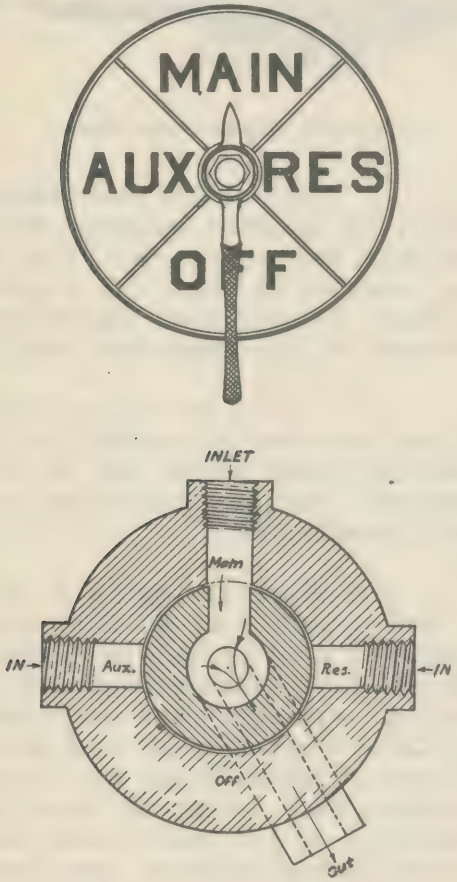


Fig. 111. Fuel Cock and Indicator Dial.

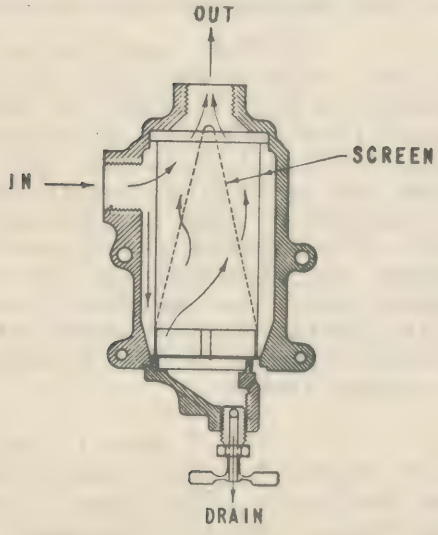


Fig. 112. Fuel Strainer.

(5) **Strainers.**-- (a) The main strainer installed in a fuel system is a most important item. Its function is to prevent dirt or other foreign matter from entering the fuel pump and carburetor, and by virtue of its low position to trap any small amount of water which may be present in the system. A drain is provided at the bottom for frequent draining, and the entire screen may be easily removed for cleaning. Fig. 112 shows a sectional view of a common fuel strainer.

(b) Strainers of fairly coarse mesh are installed in the fuel tanks on the outlet connections as shown in fig. 108. Their function is quite obvious and requires no particular comment.

(c) The carburetor body generally incorporates a small strainer of sufficient capacity to stop foreign matter which passes through the main strainers as well as particles which are introduced when fuel lines are removed. The carburetor strainer usually requires cleaning less frequently than the main strainer.

(6) **Pumps and Relief Valves.**
(a) Fuel pumps are required to furnish fuel prior to starting an engine and to deliver a continuous supply at the proper pressure at all times during engine operation. The various pump types are listed separately as follows:

(b) The hand pump (often called "wobble" pump) is generally located fairly near other fuel-system units and is operated by suitable levers from the pilot's compartment. The common design is very reliable and quite simple in operation. By reference to fig. 113, the path of fuel flow is easily followed. It will be noted that the chambers which are not delivering fuel are being filled and will discharge when the handle motion is reversed. These pumps must be installed in a vertical position in order to secure proper action of the check valves. The inlet and outlet connections are in most cases marked on the pump body.

(c) The most common engine-driven fuel pumps used in airplane fuel systems are of the eccentric sliding-vane type. Fig. 114 shows the principle of

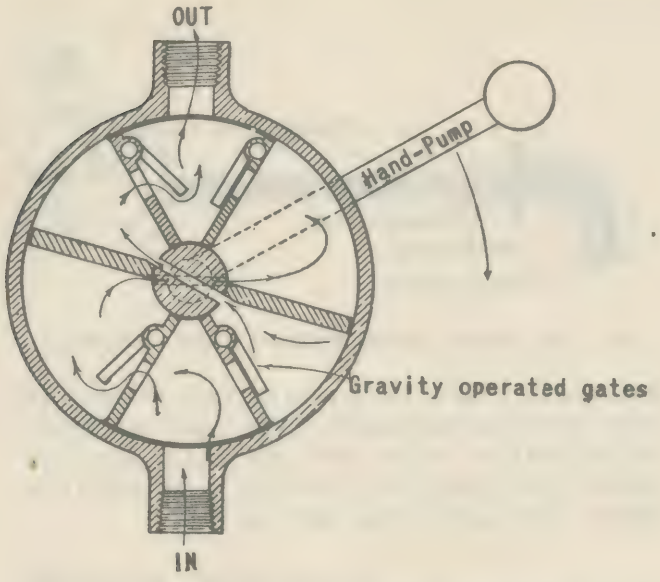


Fig. 113. Hand Fuel Pump (Wobble Pump).

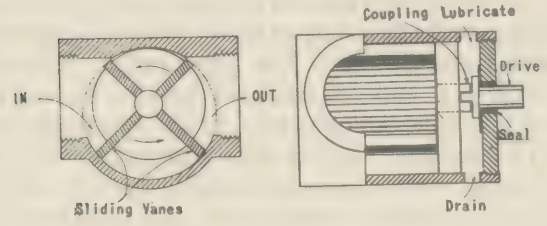


Fig. 114. Engine-Driven Fuel Pump (Vane Type).

operation of this type of pump. When the pump rotor is turned in the direction indicated, the vanes move the fuel from the inlet to the outlet of the pump. Since the pump is symmetrical about a vertical axis, it will pump in either direction with equal efficiency. Reversing the direction of rotation has the same effect as changing the pump on the mount 180°. Most pumps of this type are plainly marked to indicate the discharge port for either direction of rotation. At the point where the drive member enters the pump body it is necessary to provide a seal to prevent fuel leakage. The seal is generally a hardened steel member held by end pressure against one pump bearing. Very little trouble is experienced with this type of seal in service; however, a drain line is provided to drain fuel in case the unit becomes worn or distorted.

(d) The action of a relief valve is best explained by considering its operation in conjunction with a fuel pump (fig. 115). In order to furnish a constant

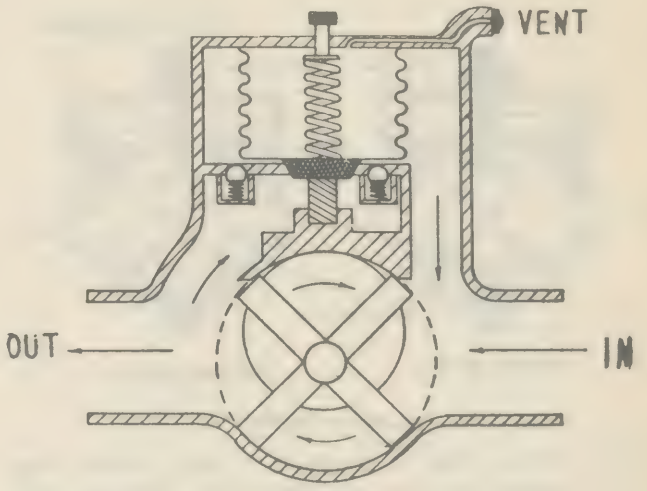


Fig. 115. Combination Fuel Pump, Relief Valve, and By-Pass Valve.

fuel supply to the carburetor under all conditions, a fuel pump is designed to deliver much more fuel at any speed than the engine actually requires. Therefore, a spring-loaded relief valve is placed parallel with the pump in order to relieve the surplus fuel to the intake side of the pump. By adjusting the spring tension in the relief valve, the differential pressure generated by the pump is accurately controlled. The bellows or diaphragm incorporated in the relief valve is essential for two reasons: It provides for air venting from a ramming air intake or external supercharger, and by its balancing action helps to maintain constant discharge pressure regardless of variations in pressure on the suction side of the pump. When not connected to air pressure, the interior of the bellows or diaphragm is left open to atmospheric pressure through a small restricted fitting. When properly connected, a single relief valve will accommodate both the hand pump and engine-driven pump. A by-pass feature, which permits fuel flow through the valve assembly, is also provided so that the unit may be used in varied fuel-system applications.

(e) In certain installations the escape of fuel through the pressure relief valve has aggravated vapor formation in the system with resultant loss of pumping efficiency. This effect has been most noticeable in systems using high-pressure carburetors and/or external superchargers when operating at high

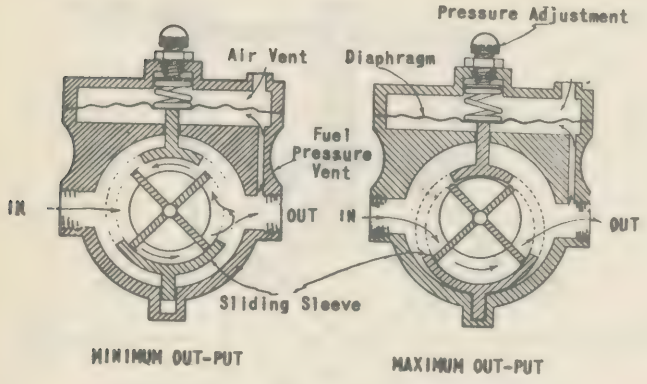


Fig. 116. Variable-Volume Fuel Pump.

altitudes. The escape of fuel from the high pressure side of the pump through the relief valve often causes vaporization of fuel in the passages. To remedy this condition, a variable-volume fuel pump having no relief valve may be used. In this type of pump a heavy diaphragm, actuated by fuel pressure, regulates the position of the pump sleeve with respect to the rotor. Fig. 116 illustrates the principle of the variable-volume pump. Note that the actuating force on the diaphragm is fuel discharge pressure against an adjustable spring. By this arrangement, the pump sleeve assumes the proper position to deliver the required volume of fuel to the carburetor at the proper pressure. Any variation in pressure from the correct setting will produce an immediate readjustment of the sleeve position. The space above the diaphragm is normally vented to the carburetor air intake pressure in order to maintain correct differential pressure. The general installation and hook-up of the variable-volume pump is quite similar to pumps having relief valves.

(f) The handling of volatile aircraft gasoline requires special care in the location of the fuel pump in the plumbing circuit. In general, the pump should be below the fuel tanks and as near to them as possible in order to avoid vapor locking difficulties. This arrangement often places the pump several feet from the engine and necessitates a remote pump drive.

1. The most common pump drive is illustrated in fig. 117. The essential units are a flexible drive shaft and the necessary adapters and couplings. Although the drive assembly requires periodic inspection and lubrication, it

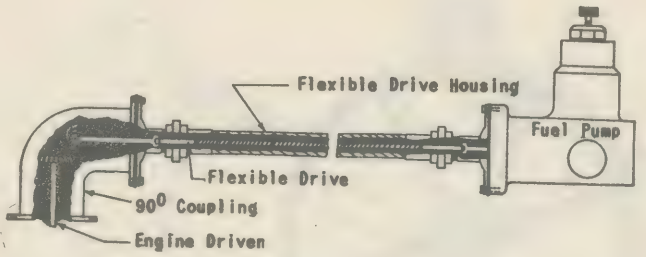


Fig. 117. Remote Flexible Drive-Shaft Assembly.

has contributed to definite improvement in fuel pump performance. This type of drive is suitable only for installations in which the pump is located a relatively short distance from the engine.

2. In larger airplanes the desired pump position may be several feet from the engine, and so a hydraulic pump drive is often installed. By reference to fig. 118 the operating principles are easily understood. The hydraulic circuit is entirely independent of other hydraulic units on the airplane. This arrangement permits a most favorable location of the fuel pump and consequently greater reliability in engine operation. An interesting modification of the hydraulic drive is the addition of an oil regulator to vary the flow of hydraulic fluid according to the fuel requirements of the engine. This variable speed hydraulic drive has been used quite effectively on certain airplanes. It is important to distinguish clearly between the variable speed fuel pump and the variable volume pump.

3. Electric fuel pump drives are also entirely practical and may be used in certain airplanes. This method of drive offers the same advantages as the hydraulic type in regard to optional pump location and is somewhat easier to install. Obviously, only an explosion-proof motor of special design is satisfactory for driving fuel pumps.

(7) **Warning Signals.**--(a) In airplanes having a number of fuel tanks there is some danger involved in allowing the fuel supply in one tank to become exhausted before switching the selector to another tank. Quite often the pilot may be engaged in other duties and fail to notice the low fuel supply until the engine misfires from a lean mixture. Under such

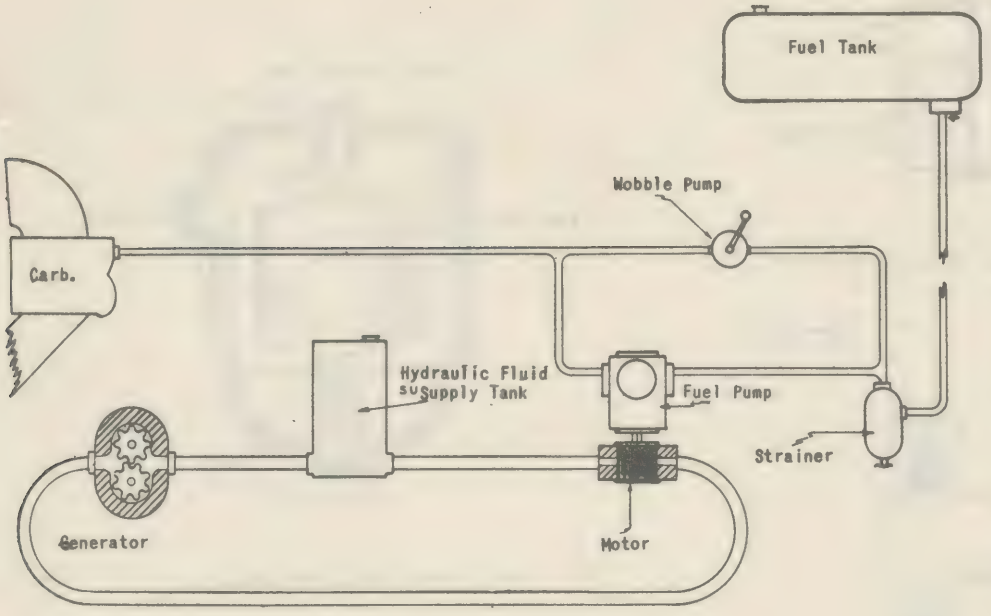


Fig. 118. Hydraulic Fuel-Pump Drive.

circumstances immediate action is required in order to prevent engine failure. To eliminate this danger, fuel pressure warning signals are employed.

(b) The actuating mechanism of the fuel pressure warning signal is a diaphragm (or bellows) vented to fuel pressure on one side and to carburetor air pressure on the other side. The diaphragm is mechanically connected to electrical-contact points (fig. 119). The contact points are in turn connected to a source of power and to a red light in the pilot's compartment. During normal engine operation the fuel pressure is sufficiently high to keep the contact points open so that the light remains off. But when a serious loss of pressure occurs, the points close, and the red light warns the pilot of the low-fuel pressure. This device is most effective when used in conjunction with carburetors which store a small amount of fuel in the supply chambers. The signal switch is installed very close to the carburetor and on the same level to eliminate pressure errors. Restricted fittings, such as those used in the fuel-pressure gage line, must not be installed between the carburetor and the warning signal. Carburetors which require continuous pressure to discharge the fuel will cut out very quickly after the initial drop in fuel pressure, and therefore on such systems the warning signal does not give adequate warning of fuel system failure.

(8) **Pressure Gage.**--The fuel-pressure gage is a differential pressure indicator with two connections on the case (fig. 120). The air connection is vented to the carburetor air intake and the fuel connection is connected to the fuel-pressure chamber of the carburetor. Thus, the gage indicates the difference between the fuel pressure entering the carburetor and the air pressure at the carburetor inlet. In some systems having no external supercharger or

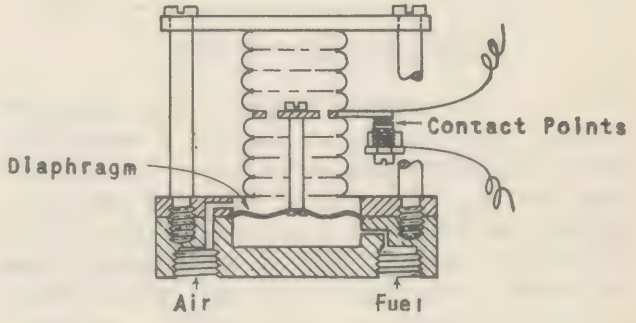


Fig. 119. Fuel Pressure Warning Signal.

ramming air intake, the air fitting on the gage is open to normal atmospheric pressure. In order to dampen pressure impulses which cause pointer fluctuation, a restricted fitting is installed at the carburetor end of the fuel-gage line. The correct fuel pressure value depends upon the type carburetor. In this connection it must be remembered that the fuel-pressure gage indicates the pressure existing at the carburetor only if it is installed at the same level as the carburetor. If the gage is located above the carburetor, the reading will be lower than the carburetor pressure, and if the gage is below the carburetor, it will read higher than normal. In certain airplanes, correction must be made for this factor in order to determine the exact fuel pressure at the carburetor inlet.

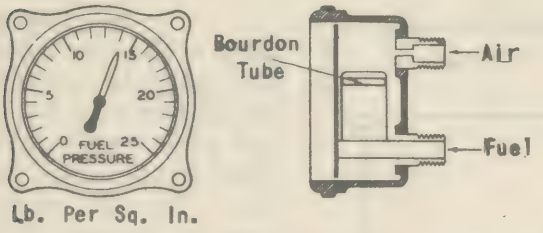


Fig. 120. Fuel-Pressure Gage (Sectional View).

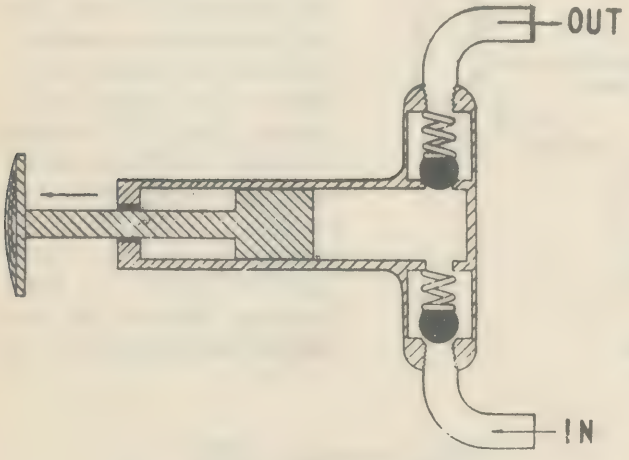


Fig. 121. Engine Primer.

(9) **Primer Pumps.**--The standard primer pump is essentially a manually operated piston pump with inlet and outlet check valves (fig. 121). Fuel for the primer may be supplied from almost any point in the fuel system. The fuel discharged from the pump is generally injected into a number of intake pipes on the engine, in most cases into the upper cylinder pipes on the radial type of engine. The procedure to be followed in priming engines varies according to the type and the atmospheric temperature, a greater priming charge being required in cold weather. When not in use the plunger should be placed in the "off" position to prevent fuel from flowing into the induction system when the engine is in operation.

(10) **Vapor Eliminators.**--In many fuel systems an appreciable amount of fuel vapor is often present in the fuel pressure line connected to the carburetor. The vapors are due chiefly to the action of the mechanical pump, especially when the pressure on the pump inlet is quite low. A float-type carburetor is not disturbed to any great extent by a small amount of fuel vapor, because the float chamber vents permit the vapor to escape. However, many

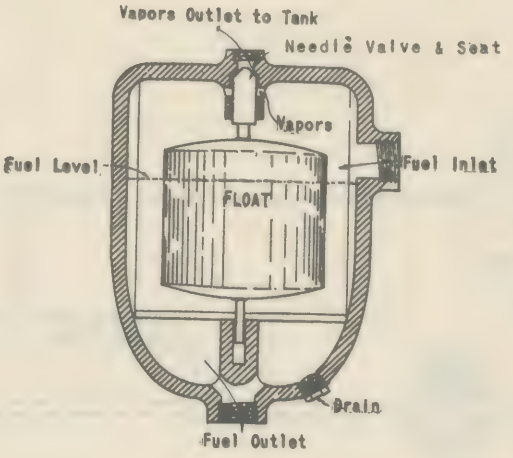


Fig. 122. Vapor Eliminator.

high-pressure carburetors and mechanical fuel injectors will malfunction due to vapor formation. To remedy this condition vapor eliminators are employed. The general internal mechanism of a vapor eliminator is shown in fig. 73. The unit is normally installed in the pressure line immediately preceding the carburetor or injector. In operation, the upper part of the housing contains a small amount of vapor and the lower part contains fuel. When the vapor content increases, the float drops slightly thus opening the needle valve and permitting some vapor to escape. As the vapor escapes, the liquid level rises and the float closes the needle valve to prevent a loss of fuel. The needle valve operation is generally rather intermittent but entirely effective in disposing of fuel vapors. The outlet connection returns the vapor to one of the fuel tanks. Some carburetors are built with a small vapor eliminator as an integral part of the carburetor assembly.

(11) **Liquidometers.**--Tank content gages or liquidometers are practically all of the float type but differ in the methods employed in transmitting the indication to the instrument panel. Three methods are in common use: direct mechanical type, hydraulic type, and electrical type (figs. 123,124,125). Adjustments are normally provided on all types for both range of operation and pointer position in order that the indicator will be accurate

throughout its scale. Each type has particular methods of adjustment so a general system cannot be given. Some designs employ a single indicator with a selector switch for a number of individual tank units.

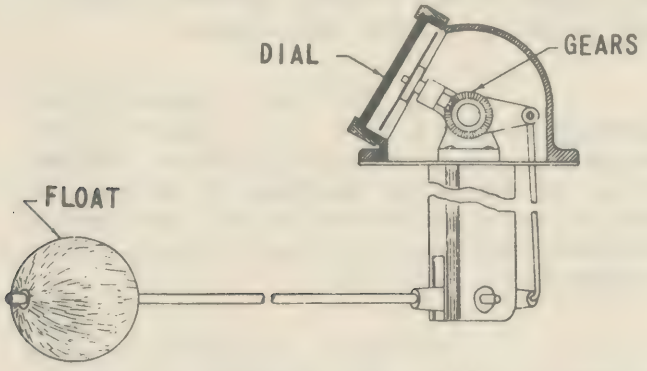


Fig. 123. Mechanical Liquidometer.

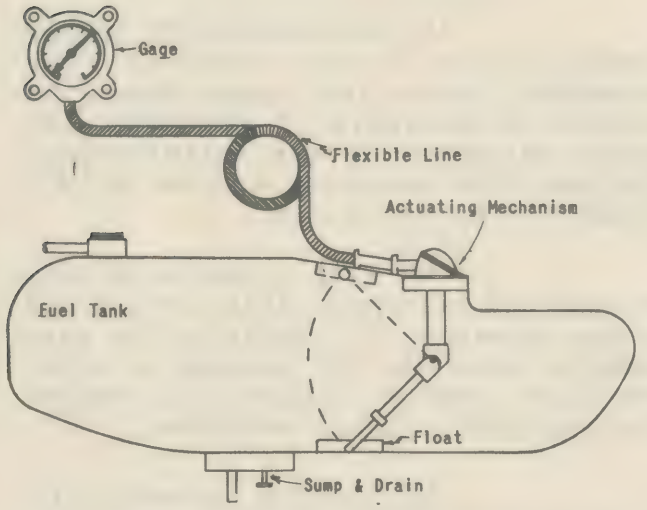


Fig. 124. Hydraulic Liquidometer.

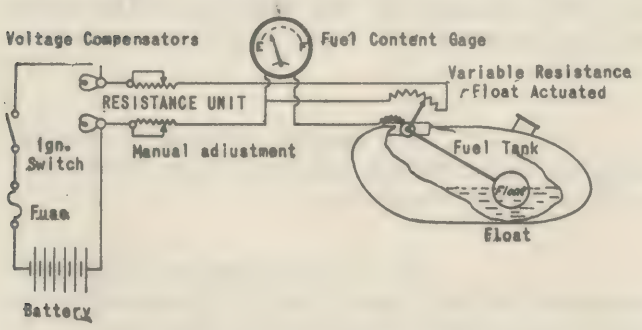


Fig. 125. Electric Liquidometer.

d. Typical Fuel-System Circuits.--(1) The essential units and circuits of a typical single engine airplane fuel system are illustrated in fig. 126. This diagram is not intended to apply to any specific airplane but represents standard principles of fuel-system arrangement. Attention is called to the installation of the pressure gage and warning light switch. The system as shown is adaptable to airplanes having ramming air intakes and external superchargers.

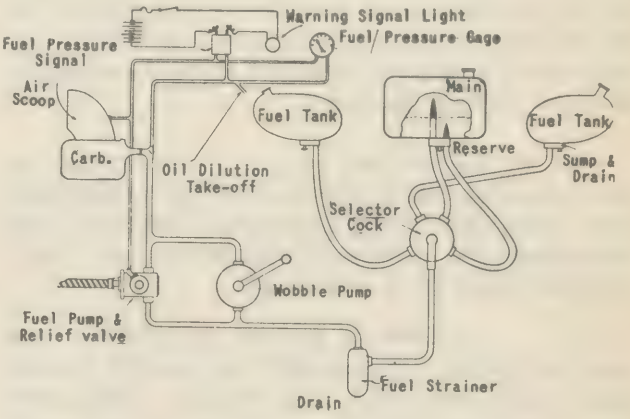


Fig. 126. Single-Engine Fuel System.

(2) The twin engine fuel system (fig. 127) is essentially a pair of single engine systems plus the arrangement for interconnecting the two systems by a suction or pressure cross feed line. With this circuit it is possible to operate both engines with only one engine pump and to supply fuel to one or both engines from either set of fuel tanks. Continued addition of units and lines, using these same principles will give fuel system circuits for airplanes having more than two engines.

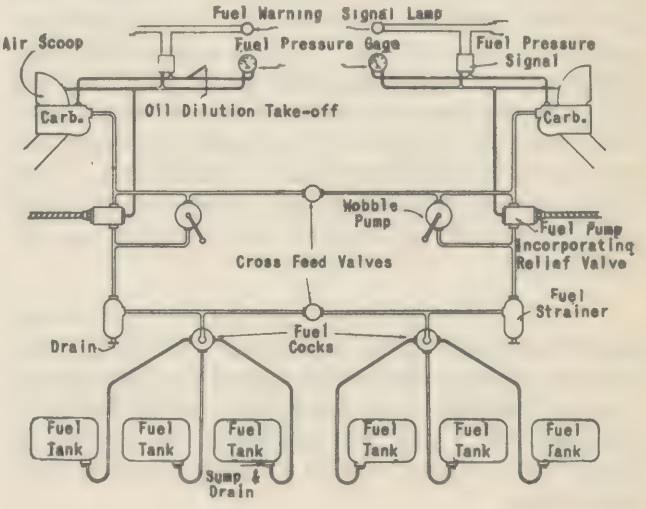


Fig. 127. Twin-Engine Fuel System.

(3) In many airplanes having a large number of small fuel tanks, the pilot

must give frequent attention to the fuel selector valve and tank contents' gage. To relieve the pilot of this duty, much development has been accomplished in the design of completely automatic fuel systems. Such systems require very little attention in flight and are quite reliable in operation. Provisions are generally retained for manual control if the automatic feature is not desired.

e. Operation.--(1) In addition to the specific data pertaining to individual type airplanes, the following instructions regarding the general operation of fuel systems should be observed:

(2) During ground operation, the tank selector cock should be placed in all tank positions with the engine operating as a check on the fuel flow from each tank. The fuel pressure gage reading should be observed and the pressure adjusted if necessary. The signal light is checked for proper operation, and the liquidometer indication on all fuel tanks should be noted. In multi-engine airplanes each system is checked separately with the cross feed valve in the "off" position.

(3) Take-off is accomplished with the fuel tank selector cock turned to a tank which is known to contain an adequate fuel supply. When both main and reserve fuel supplies are carried in the same tank, the fuel cock will be placed in the reserve position prior to take-off. When switching fuel tanks in flight, the selector cock is moved to the proper position and, if any fluctuation in fuel pressure is observed, the hand pump may be used. Under no circumstances should the hand pump be operated in such a manner as to create excessive fuel pressure. The same general instructions concerning fuel system operation apply in landing as in take-off.

(4) During normal tactical maneuvers most fuel systems are entirely reliable and require no special considerations. However, no standard systems are designed to function properly in inverted flight or during other unauthorized maneuvers.

f. Maintenance.--(1) **The maintenance requirements of fuel systems and units may be itemized as follows:**

(a) Fuel tanks are checked for security of mounting, dents, or leaks, and the sumps will be drained periodically.

(b) Lines and fittings must be inspected for cracks, proper support, and security of nuts and clamps.

(c) Fuel cock controls are rotated to check for free operation, backlash, and accuracy of pointer indication. If excessive backlash is noted, the entire operating mechanism will be checked for worn universal joints, loose pins, broken drive lugs, etc.

(d) Fuel strainers require periodic draining and cleaning of screens.

(e) Hand pumps should operate freely and develop the required fuel pressures. The engine pumps should be checked for security of mounting and proper adjustment of the relief valve. The pump drive mechanism requires periodic inspection and lubrication.

(f) Fuel pressure warning signals can be conveniently checked for proper adjustment by operating the hand pump and observing the pressure at which the light comes on. Adjustment is sometimes required in the contact mechanism.

(g) Engine primers are checked for free operation and for signs of fuel leakage at the packing. Adjustment or replacement of the packing may be necessary.

(h) Vapor eliminators are checked for leakage and for proper operation of the float mechanism.

(i) Liquidometers must be accurate at all tank levels from empty to full positions. Adjustments for range and position are frequently required.

(j) The entire fuel system is carefully inspected for proper safetying, wear, or damage of any description. A final check is made by observing closely the fuel system action with the engine operating.

Section III ENGINE LUBRICATION

1. ENGINE LUBRICANTS AND LUBRICATION.

a. Kinds of Lubricants.--(1) A lubricant may be defined as a substance having greasy properties. Lubricants are used almost exclusively for reducing friction between bearing surfaces. Lubricants may also be used as rust preventives on metallic parts subject to corrosion.

(2) Common lubricants may be classified according to the source from which they are derived as:

(a) Animal lubricants
(b) Vegetable lubricants
(c) Mineral lubricants.

b. Animal Lubricants.--Animal lubricants, such as tallow, tallow oil, lard oil, neats foot oil, sperm oil, and porpoise jaw oil, are excellent lubricants provided they are not subjected to high temperatures. They are not suitable for lubricating internal combustion engines, as above certain temperatures they throw off fatty acids. Due to their comparative high stability at normal temperatures, animal oils are used extensively for lubricating guns, sewing machines, and other light machinery such as clocks, etc. Porpoise jaw oil, used for lubricating expensive watches and delicate mechanisms, is an excellent high quality animal oil.

c. Vegetable Lubricants.--(1) Vegetable lubricants, such as castor oil, olive oil, cottonseed oil, and rape oil, have excellent lubricating qualities but tend to oxidize when exposed to the atmosphere. The vegetable and animal oils have a lower coefficient of friction than mineral oils but wear steel away more due to loosening the bonds of iron at the surface. In this respect cottonseed oil is a good cutting oil for hard steels.

(2) Castor oil has a very flat viscosity curve and more oiliness than any other oil. It will run engines in which the pistons seize in a very few minutes at full throttle with mineral oil. However, it oxidizes readily, causing bad gumming, resulting in ring-sticking and restriction of flow through a small metering orifice. As vegetable oils are nonsoluble in gasoline, castor oil was used to an advantage in early rotary types of internal combustion engines in which the crankcase was part of the induction system. In high powered racing automobile engines, castor oil may be a highly desirable lubricant in view of the fact that these engines are operated only for a short length of time between overhaul periods.

d. Mineral Lubricants.--(1) Mineral lubricants have many properties suitable for use in the lubrication of internal combustion engines and are used almost exclusively in their lubrication.

(2) Mineral lubricants may be readily classified according to their physical properties as:

(a) Solids
(b) Semi-solids
(c) Fluids.

(3) *Solid Lubricants,* such as mica, soapstone, and graphite in finely powdered form, serve to fill the low spots in a typical bearing surface to form a perfectly smooth surface and at the same time to provide a slippery film to reduce friction. A finely divided, not too hard, solid lubricant also acts as a mild abrasive, smoothing the surface previously roughened by machining or excessive wear. They are fairly satisfactory on slow speed machines, but lack the ability to dissipate heat which is often an essential requirement. Certain solid lubricants have the ability to carry heavy loads and

for this reason are often added to fluids to reduce wear between surfaces subjected to high unit pressures.

(4) **The Semi-solid Lubricants** include such substances as extremely heavy oils and greases. Modern industrial operations require a very great number of such lubricants for special applications. Grease is composed of a mixture of soap with oil. In general, sodium soap is used in grease for gears and hot running equipment, calcium soap in cup grease, and aluminum soap in high pressure and ball bearing grease. The soaps are usually cleates or stearates. Greases give good service when applied periodically, but because of their consistency they are not suitable for continuous or circulating lubrication systems.

(5) **Fluid Lubricants** or oils are universally used as the principal lubricant in internal combustion engines for many reasons. They may be readily pumped or sprayed, provide a good cushioning effect, and are effective in absorbing and distributing heat.

e. Engine Lubricating Oils.--(1) **General.**--The source of lubricating oils is petroleum, the same as that for the volatile fuel gasoline. Each of the series of compounds which make up gasoline continues right on, with rising boiling points, through kerosene and heavy fuel oils until we come to the constituents of the lubricating oils which have boiling points in the region of 400° to 500°C. The last two products to form during the distillation of petroleum are known as wax distillate and cylinder stock. The former is dewaxed in filter press, filtered, etc., to give neutral stock. The latter is dewaxed and refined to give bright stock. The various grades of lubricating oils are then obtained by blending neutral and bright stocks in different proportions. In some vacuum distillation processes, the entire lubricating oil fraction is distilled over, this being possible without excessive temperature due to the lower boiling point at reduced pressure. In this case the cylinder stock is not refined to give bright stock, but instead the various grades of lubricating oil are obtained by fractional distillation of the lubricating oil portion of the petroleum.

(2) **Function of Engine Oil.**--The oil in an internal combustion engine performs three important functions:

(a) Acts as a lubricant, thereby reducing the friction between moving parts.

(b) Acts as a seal for the combustion chamber and prevents the loss of compression past the piston rings.

(c) Acts as a cooling medium and cools the various parts of the engine.

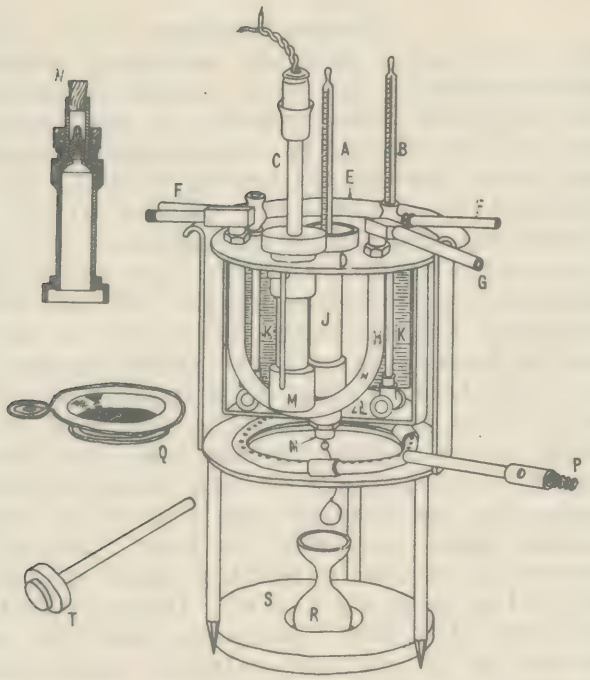
(3) **Properties of Lubricating Oils.**--(a) Since mineral oils are produced in many grades, it is highly important to examine particular specifications when selecting oils for use in internal engines. Of special significance are the factors:

1. Viscosity
2. Flash point
3. Pour point
4. Carbon residue.

(b) Other characteristics which are of lesser importance, but which, if extremely poor, should eliminate the consideration of that oil as a suitable lubricant are:

5. Acidity and alkalinity
6. Corrosion
7. Emulsion
8. Color.

(4) **Viscosity.**--(a) Viscosity is a measure of the fluid friction of a liquid and is also referred to as the resistance to flow or the body of an oil. Thus if an oil flows slowly, it is described as a heavy bodied oil, viscous oil, or an oil of high viscosity. The body or viscosity of an oil determines the amount of viscous drag or fluid friction. For any given set of conditions, the higher the viscosity, the greater the load the oil will support. In general it is desirable to select an oil of the lowest viscosity which will provide an unbroken film, so that drag may be held to a minimum. However, viscosity of an oil decreases with a rise in temperature and when it is considered that the oil must often operate through a wide temperature range, the problem of selection might become a very complex one and one worthy of extensive study.



A.	Oil tube thermometer.	K.	Stirring paddles.
B.	Bath thermometer.	L.	Bath vessel.
C.	Electric heater.	M.	Electric heater receptacle.
D.	Turntable cover.	N.	Outlet cork stopper.
E.	Overflow cup.	P.	Gas burner.
F.	Turntable handles.	Q.	Strainer.
G.	Steam inlet or outlet.	R.	Receiving flask.
H.	Steam U-tube.	S.	Base block.
J.	Standard oil tube.	T.	Tube-cleaning plunger.

Fig. 128. Saybolt Viscosimeter (Sectional View).

(b) The viscosity of an oil is measured in seconds of time required for 60 c.c. of the oil, at a specified temperature, to flow through a given outlet orifice in a Saybolt Standard Universal Viscosimeter, fig. 128. For example, if the time required for a particular sample of oil is 120 seconds at 210°F., the oil is said to have a Saybolt Viscosity of 120 seconds at 210°F.

(c) In order to simplify the selection of oils, the Society of Automotive Engineers has adopted an S.A.E. rating system which divides all oils into seven groups according to viscosities at 130°F. or 210°F. These S.A.E. ratings are purely arbitrary and bear no direct relationship to the Saybolt or other viscosimeters. They are defined, however, in terms of the Saybolt Universal Viscosity. Grades No. 10 to No. 40 are tested at 130° F. and the heavier oils are tested at 210° F., a procedure which is quite normal since the heavier oils are intended for use at higher engine temperatures.

(d) To determine the S.A.E. rating of an oil sample, it is first tested at a proper temperature in the Saybolt viscosimeter. The reading thus obtained is compared with the ranges listed on the chart.

(5) **Flash Point.**--(a) The lubrication of cylinder walls and pistons of internal combustion engines requires consideration of factors other than oil viscosity. Because of the large amount of heat generated in cylinders during the power stroke, the flash test of an oil assumes considerable importance. The test is performed by heating an oil sample in an open cup, and as the temperature rises, a flame is periodically passed slowly over the surface of the oil. The first test which momentarily ignites the oil vapor above the cup is recorded as the flash point.

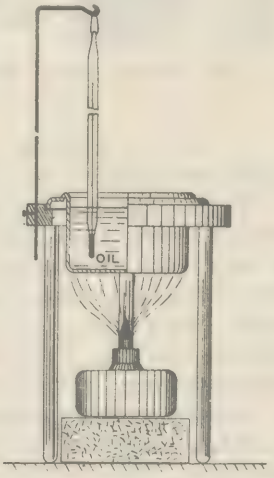


Fig. 129. Open Cup Flash Test Apparatus.

(b) Other factors being equal, an oil of high flash test is preferred because of the greater degree of protection afforded cylinders and pistons and the probable lower oil consumption during continuous engine operation. A fire point test, which indicates the temperature of continuous burning, is often performed along with the flash test, but this specification is considered of little importance in aircraft engine oils

(6) **Pour Point.**—(a) Cold weather starting and operation also require special consideration. It is not at all uncommon for internal combustion engines to be started cold at temperatures of 0°F. or below. Low temperature oil viscosities reach surprisingly high figures, which of course, necessitates a very high cranking torque in order to rotate the engine. Furthermore, at certain low temperatures oil will congeal or chill completely so that circulation is impossible even if starting is accomplished by special means. Unless a method of heating the oil supply is practicable, the heavier grades of oil are not satisfactory for cold weather operation; an S.A.E. No. 40 is the lowest viscosity oil which is satisfactory for the average aircraft engine operating in extreme cold weather.

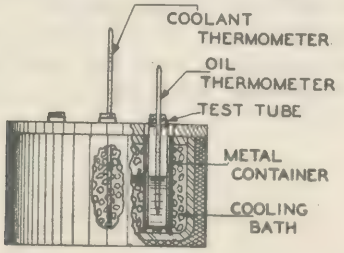


Fig. 130. Pour Test Apparatus.

(b) In regard to the question whether a low pour point or a good viscosity curve (high viscosity index) is best for low temperature starting of internal combustion engines, experience indicates clearly that both are essential. The viscosity curve must be good and the pour point should be within 5°F. of the average starting temperature. The pour point of an oil is the lowest temperature at which it will pour or flow when it is chilled, without disturbances. The oil to be tested is placed in a glass test jar and cooled in a cooling bath until it ceases to flow when the test jar is removed from the bath and held in a horizontal position for exactly five seconds. This test is often called the cold test.

(c) The oil dilution system and hopper type oil tank, discussed elsewhere, provide a solution to the problem of maintaining comparatively low oil viscosities in cold weather to facilitate starting, and at the same time meet the high temperature requirements of continuous operation.

(7) **Carbon Residue.**--It is of some importance that the amount of carbon deposited by the oil in an engine is known. Although low carbon residue is desirable, the desired viscosity temperature characteristics should not be sacrificed, particularly in aircraft engine oils. A laboratory test may be accomplished with a Conradson Carbon Residue Apparatus by evaporating a known weight of oil and weighing the residue. It is not a sure indication of the relative carbon deposits that may form. It has been found that the volatility characteristics are a better guide as to carbon residue than the Conradson carbon test. If the distillation curve for the heavier ends runs high, the carbon deposition will be high. Investigation of various oxidation tests of oils is being made by the oil industry with the hope that some laboratory test can be devised which will be a reliable indication of the carbon-forming, sludging, and ring-sticking tendencies of oils.

f. Special Engine Lubricants.--(1) While oil is the principal lubricant used for the lubrication of aircraft engines, in certain cases because of special stresses or peculiar design, it is impossible or unsatisfactory to lubricate units by means of engine oil. In these cases special lubricants, generally greases, are required. For example, a grease for the coolant pump requires resistance to the action of water, whereas in a hot running unit, such as the generator, a high melting point may be most important. All engine accessories require special lubricants. Accessories are lubricated at the time of assembly during manufacture and overhaul and do not require periodic greasing while installed.

(2) The nomenclature of many of the special lubricants suggests their use or includes the name of the article in which it is used as follows:

(a) Engine rocker arm oil
(b) Thread lubricant
(c) Spark plug lubricant
(d) High melting point grease
(e) Petrolatum
(f) Rust preventive compound.

(3) **Rocker Arm Oil** is used for lubrication of radial engine rocker arms except when a grease is specified or when automatic lubrication is provided. This oil is a petroleum base product having an extremely high viscosity of 3,000 seconds at 210°F. to maintain fluidity at the high temperature to which it is subjected. It is heavy enough to be used in place of grease without the addition of soap and is superior to grease containing soap inasmuch as the soap present has poor lubricating properties as compared with oil. In addition, this oil is considerably more fluid than greases at low temperatures.

(4) **Thread Lubricant** is used on threaded parts of aircraft engines where corrosion or oxidation may cause thread seizure if a lubricant is not present. It is composed of about 75 per cent heavy mineral oil and approximately 25 per cent lead soap, resulting in a semi-fluid composition.

(5) **Spark Plug Lubricant** is used on threads of spark plugs to facilitate insertion and removal from engine cylinders. It is composed of approximately 60 per cent heavy mineral oil and 40 per cent finely ground mica.

(6) **High Melting Point Grease,** commonly called "Fibre grease," is used for lubrication of hot running equipment, particularly electrical equipment. It is composed of mineral oil and sodium soap and varies in consistency from hard to soft.

(7) **Petrolatum** may be used as a light petroleum grease or as a combined lubricant and rust preventive. It is a pure refined mineral oil. It is also used on aircraft battery terminals.

(8) **Rust Preventive Compounds** are used to prevent corrosion of unpainted metal surfaces of aircraft engines in storage. It is furnished in two grades; a heavy grade for external application which can be readily removed from metal surfaces by use of kerosene as a solvent, and a light grade for internal surfaces of engines, which does not require removal when the engine is prepared for operation. The light grade is composed of 90 per cent vegetable oil, 7 per cent alcohol, and 3 per cent triethanolamine. This solution is particularly effective in preventing corrosion of cylinder barrels, valves, and valve mechanisms from the use of ethyl fuels. The only vegetable oil known to be applicable to this compound is castor oil.

g. Types of Lubrication Systems and Requirements.--An engine has many parts that are in motion, either reciprocating or rotating. Every moving part must be guided in its motion or kept in a given position during its motion. This necessitates more or less contact between surfaces having motion relative to each other, which introduces friction. This friction takes available energy, in the form of work on the piston and transforms it into heat at comparatively low temperatures, and thus reduces the power output of the engine; also, whenever metallic friction occurs there is bound to be wear. The object of lubrication and lubricants is to interpose and maintain a film of lubricant between the various moving surfaces, thus reducing metallic contact, power loss, and wear to a minimum.

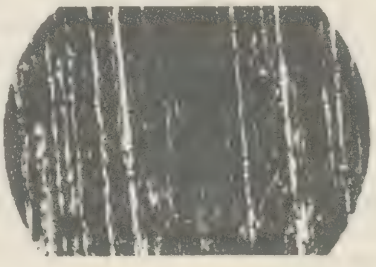


Fig. 131. Micrograph Showing Bearing Surface Magnified 100 Times.

(1) **Friction.**--(a) A smooth surface, when examined under a miscroscope, appears to be made up of ridges and valleys. Two surfaces in contact have some of the ridges on one surface in the valleys on the other surface, and vice versa. When one surface slides over the other, the interlocking surface particles offer a resistance known as **SLIDING FRICTION.**

(b) A cylinder or a sphere with a smooth surface when placed in contact with a plane surface will deform not only its surface, but also the plane surface. This permits some interlocking of surface particles besides what would occur with a perfect line or point contact, and the resistance offered to rolling the cylinder or sphere over the surface is known as **ROLLING FRICTION.**

(c) Rolling friction as encountered in ball bearings is less than that encountered in roller bearings. Rolling friction is considerably less than sliding friction and is always preferable when the surface permits line or point contact.

(d) The amount of friction between two solid surfaces depends upon the following items:

1. Load carried by the surfaces
2. Rubbing speed of one surface on the other
3. Condition and material of which surface is made.

(e) The friction increases directly with the load. High speeds tend to decrease the friction. It is always desirable to have very smooth surfaces and to have one surface of softer material than the other for best results. In practice, owing to the irregularities in bearing surfaces, contact takes place at only a small number of points where the pressure is concentrated. The friction becomes excessive and results in wear. Hence, a plastic metal which, under pressure, can mold itself to the form of the journal and increase the area of the surfaces in contact, is desirable. Common practice is to use a soft bearing material in conjunction with hard metals.

(2) **Lubrication.**--(a) Lubrication, by definition, is the introduction of a smooth fluid or semi-fluid substance, such as oil or grease, between two moving surfaces to prevent them from coming in direct metallic contact. Friction can be reduced considerably if a fluid film can be interposed between two surfaces. In this case the fluid sticks to both surfaces and any movement results in a shearing action in the fluid. The fluid prevents metallic contact between the bearing surfaces thus substituting for metallic friction the smaller internal friction of the fluid or lubricant. In perfect lubrication the metallic surfaces do not come in contact at all, but this degree is usually not attained in practice. Only liquids with great tendency to adhere are suited for lubrication, since only these have the property to penetrate by capillarity where journal and bearing are the closest and where the danger of contact and wear is the greatest. The lubricant prevents metallic contact of bearing surfaces because of its adhesion to these surfaces and because its viscosity keeps it from being squeezed out by the pressure on the bearing.

(b) The fluid friction of the lubricant is not affected by the load or the nature of the bearing surfaces but depends upon the following items:

1. Rubbing speed
2. Area of rubbing surface
3. Viscosity of lubricant.

(3) **Lubrication System.**

(a) ***Types Most Widely Used.***--The distribution of oil to the various bearings in an engine is accomplished in various ways. The means for supplying the oil to the various bearings gives rise to the names applied to the various systems. The most widely used lubrication systems for internal combustion engines are:

1. Splash circulating system
2. Force or pressure system
3. Combination or splash and pressure system.

(b) ***Pressure Lubrication Systems.***--The pressure system will be the only system discussed here as it is used universally on aircraft engines. This system incorporates a mechanical pump which supplies oil under pressure to the various bearings. The oil flows into the suction side of the pump. The entrance to the suction line is usually located a short distance above the bottom of an oil sump so that any sediment will not be circulated. The pump, usually of a gear type, forces the oil into a manifold which distributes the oil to the crankshaft bearings. The crankshaft is drilled and oil flows from the main bearings through the crankshaft to the lower connecting rod bearings. When the oil is fed from a hole in the shaft into the bearings, it is important that the hole be located at a position where bearing pressures are at a minimum. A connection from the end bearing, or the main manifold, provides oil to a hollow

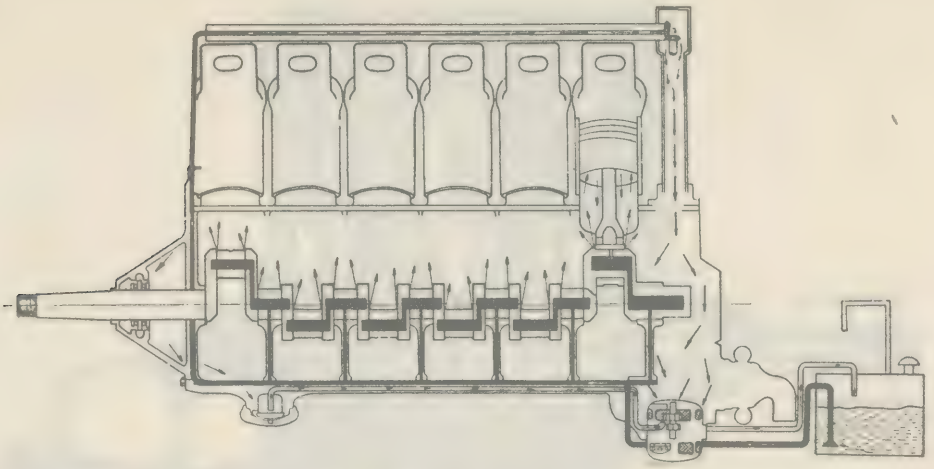


Fig. 132. Lubrication Diagram of Liberty "12A" Engine.

camshaft which distributes oil to the various cams and camshaft bearings. The cylinder surfaces obtain oil both from the spray of oil leaving the crankshaft and crankpin bearings. Under cold starting conditions an appreciable amount of time is usually required before sufficient oil reaches the cylinder wall, since it flows so slowly through the small crankpin bearing clearances from which it is sprayed on the walls.

(4) **Radial Engine Lubrication.**--The circulation of oil through a typical radial-type engine is shown in fig. 135.

(a) In the pressure part of the system, the oil enters the pump (A), which forces it through the screen or strainer (B) to the rear and front crankshaft journals. The oil is forced into the drilled passages in the rear crankshaft journal which lead to the crankpin, master connecting-rod bearing, and short-rod knuckle pins. One or more lines or passages branch from the rear crankshaft journal and lead the oil to the various rear section drive shaft bearings (C). The line branching off the front crankshaft journal leads the oil under pressure to a control valve (D), by which a hydraulic, controllable pitch propeller may be operated by the engine oil pressure directed to the connection (E). The oil pressure relief valve (F) is adjusted to obtain the desired pressure in the system, shunting surplus oil into the scavenging system or to the inlet side of the pressure pump. The dotted arrows designate oil forced out at various points in the pressure system which lubricate, by splash or spray, such as pistons, rings, cylinder walls, accessory drive gears, etc., before draining into the scavenging system sumps.

(b) In the scavenging system, an oil sump (G) located in the lowest section of the crankcase collects all the surplus oil drained from the pressure system. The screen (H), located in the sump, prevents foreign particles from restricting the flow of oil returning to the scavenging pump (I), removes the oil from the sump, and forces it back into the external oiling system for recirculation.

(c) In connection with the lubrication system, a crankcase breather (J) is installed at some point on the upper part of the crankcase to relieve internal pressure resulting from high temperatures and high-speed piston operation. Provisions are made in the construction of the breather to permit escape of the pressure without loss of oil, usually by the use of internal baffles. In some breathers a gravity-operated valve remains open in normal attitudes of the engine and closes when the engine is inverted. This is done to prevent oil from flowing out of the breather in inverted flight.

(5) **Essential Parts of a Lubrication System.**--All lubrication systems consist of either gear or eccentric vane type oil pumps, and oil pressure release valve, oil tank, oil pressure gage, oil temperature gage, and sometimes an oil radiator. The gear type oil pump is illustrated in fig. 136, while fig. 137 is an illustration of the eccentric vane type oil pump.

(a) *Oil Pressure Relief Valve.*--The oil pressure relief valve as illustrated in fig. 139 is located in either the oil pressure screen chamber or the oil pump. In the former location the valve by-passes to the rear section; in the latter location, the valve by-passes oil to the pressure stage of the pump. The oil pressure relief valve maintains the

proper oil pressure throughout the entire lubrication system, and by-passes oil (as specified when it is subject to excessive pressure).

(b) *The Compensating Pressure Relief Valve.*-- This valve retains full pump pressure until the oil has completely circulated through the oiling system.

(c) *The Thermostatic Controlled Compensating Relief Valve and Thermostat.*-- This valve works the same as the compensating pressure relief valve except that it retains full pump pressure until the oil has reached a given temperature.

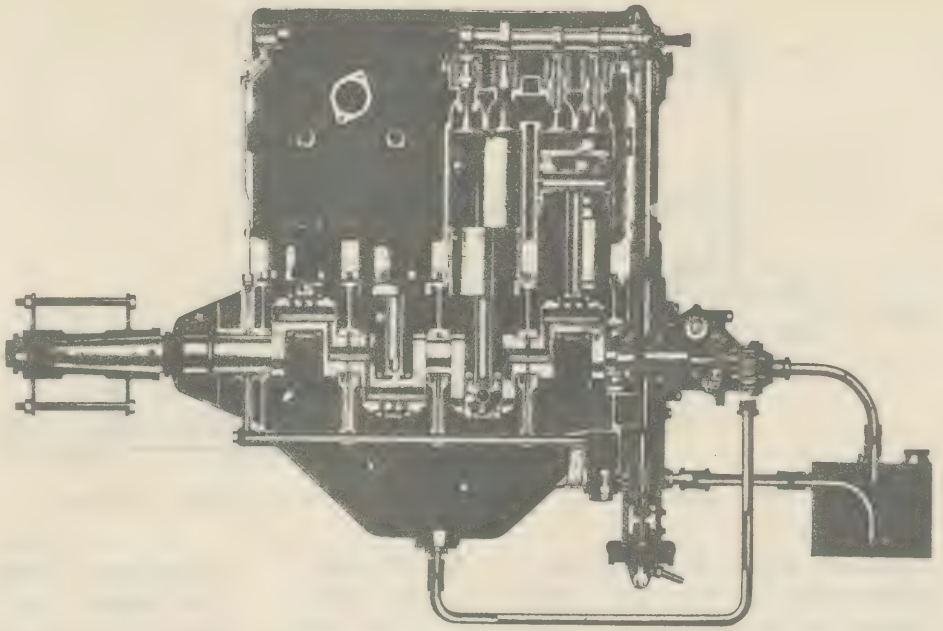
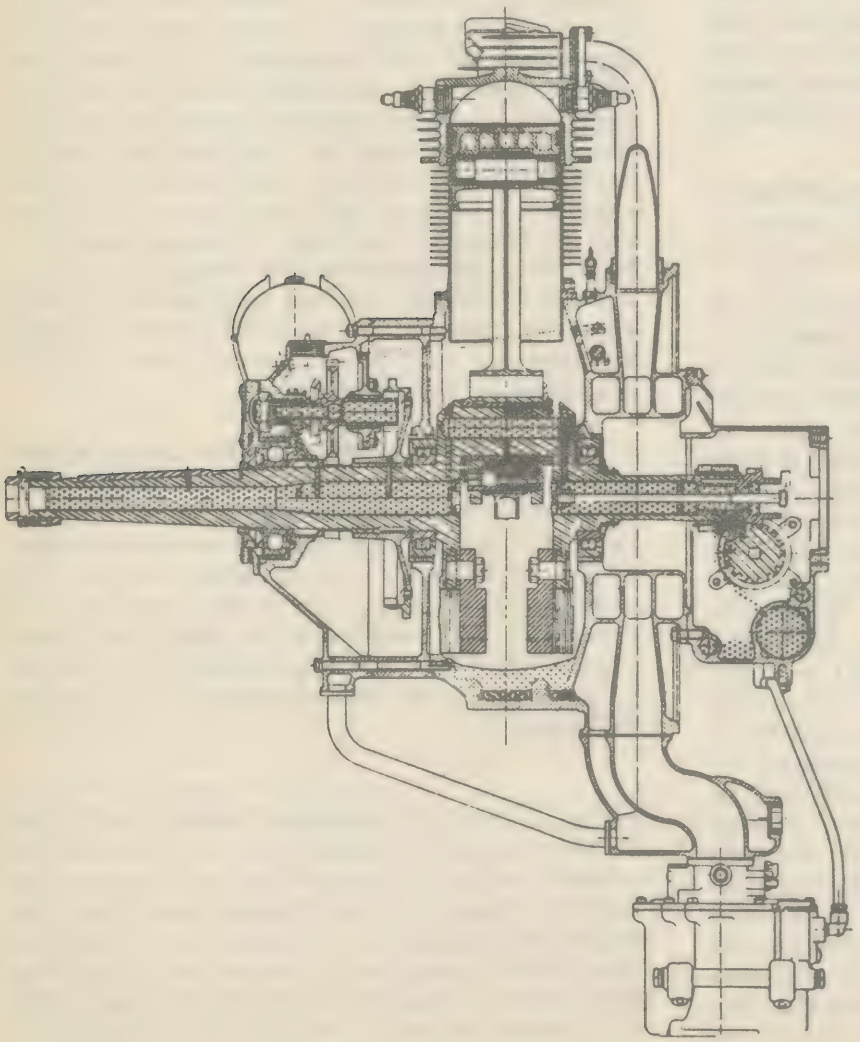


Fig. 133. Oiling System Hispano-Suiza Motor



(d) *The Oil Dilution System.*--Gasoline is metered into the oiling inlet of the screen pressure chamber. This gasoline dilutes the oil in the engine while it is idling preparatory to stopping engine. The oil dilution valve at the outgoing end of the pressure screen closes as the motor stops and traps the dilution in the engine. This dilution makes starting the engine in cold weather easier.

(6) **The Cuno Oil Filter.**--(a) The "Automatic Cuno" employs the same cartridge as the "Manually operated Cuno" except that it mounts a hydraulic motor head

Fig. 134. Wright Whirlwind Engines Model J-5 Oiling Chart.

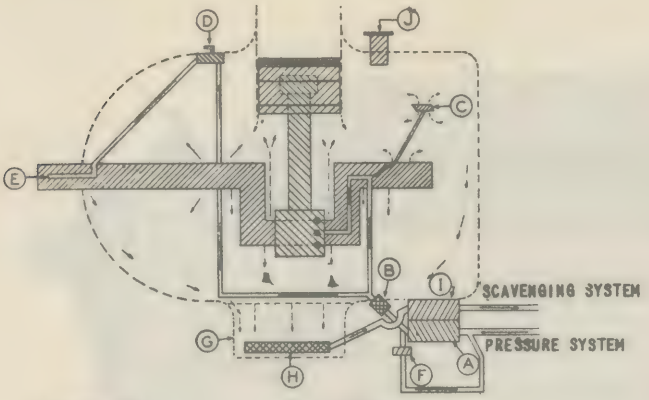


Fig. 135. Typical Radial Engine Lubricating System.

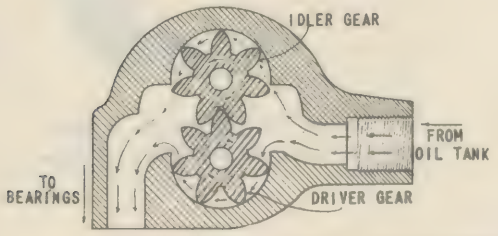


Fig. 136. Gear Type Oil Pump.

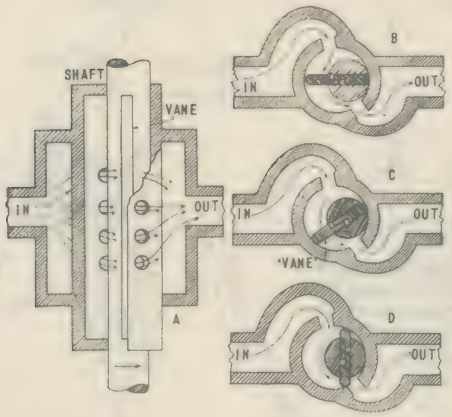


Fig. 137. Eccentric Vane Type Oil Pump.

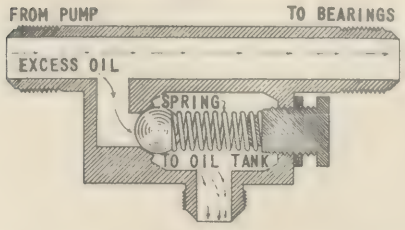


Fig. 138. Oil Pressure Relief Valve.

for the purpose of rotating the filter disc between the cleaner blades.

(b) The hydraulic head consists of: a piston within a cylinder, a steel valve operated by a springloaded toggle plate, a rocking shaft and clutch assembly.

(c) When in operation oil is directed by the valve through a passage to the cylinder where it exerts pressure on the back of the piston. As the piston moves outward, displacing the oil ahead of it which escapes through the valve to the motor head exhaust connection, it pushes on the rocking shaft which engages a single-tooth gear on the clutch ring. Here it translates the "straight-line" motion of the piston to "rotary" motion of the clutch ring which, by pinching rollers between the clutch ring and clutch center, rotates the spindle mounting the stack of discs.

(d) At the end of the "power stroke" the piston causes the toggle device to reverse a steel valve which now directs oil under pressure on the opposite side of the piston and opens a line so that as the piston returns down the cylinder, the oil that is behind the piston can escape to the exhaust connection. At the end of this stroke the toggle device again reverses the valve, starting a new "cycle of operation."

(e) On this last stroke of the piston, the rolls in the clutch assembly are not pinched, and no power is transmitted to the clutch plate or cartridge, thus providing for progressive motion of the cartridge in one direction.

(f) About sixty-six (66) revolutions of the piston will produce one (1) revolution of the filter element. Under standard operating conditions the cartridge will revolve approximately 1-1/4 r.p.m.

(g) To check operation of the Automatic Cuno Hydraulic Motor Head, remove operating nut covering manual turning shaft and replace in reverse position. Mark one face of the manual nut and note its position. Run the engine at idling speed and at the end of approximately five (5) minutes note the position of the nut.

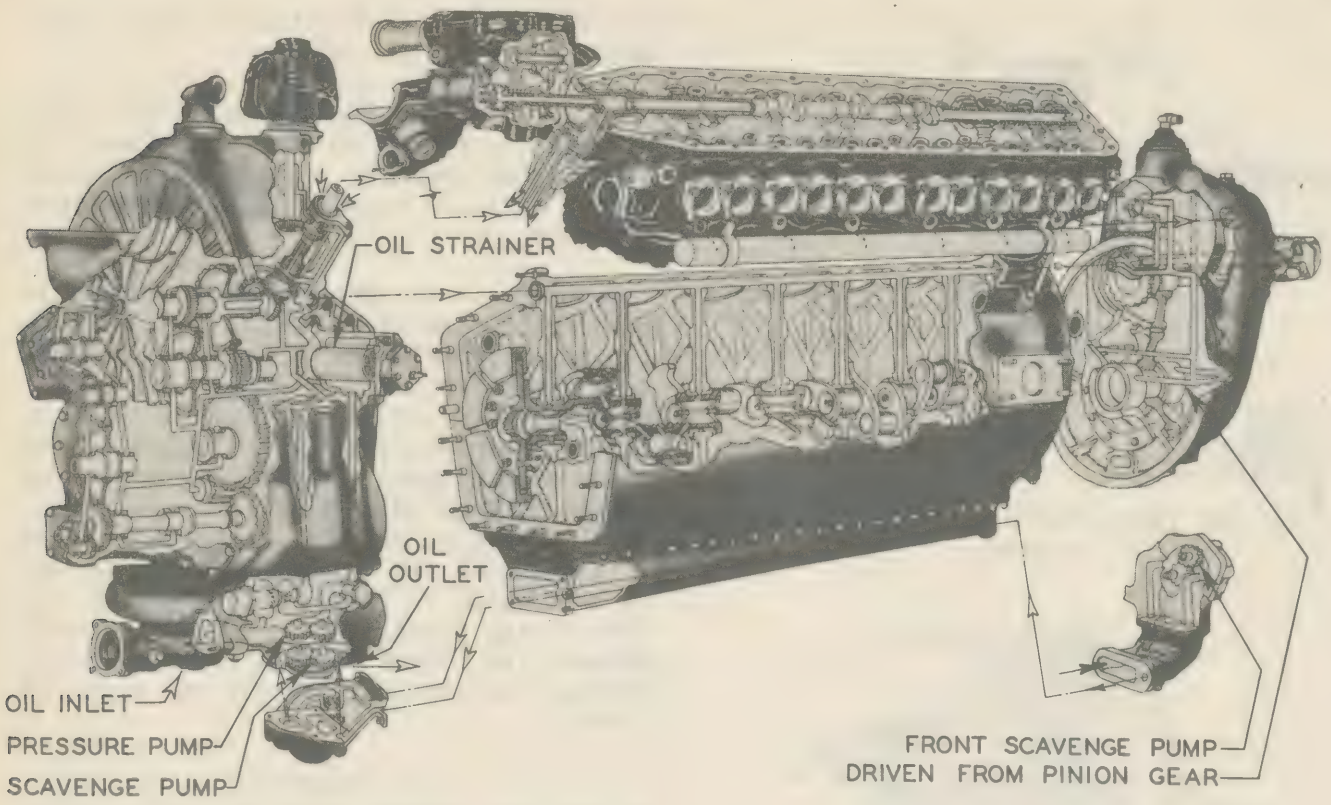


Fig. 138a. Allison "F" Type Engine Lubrication System.

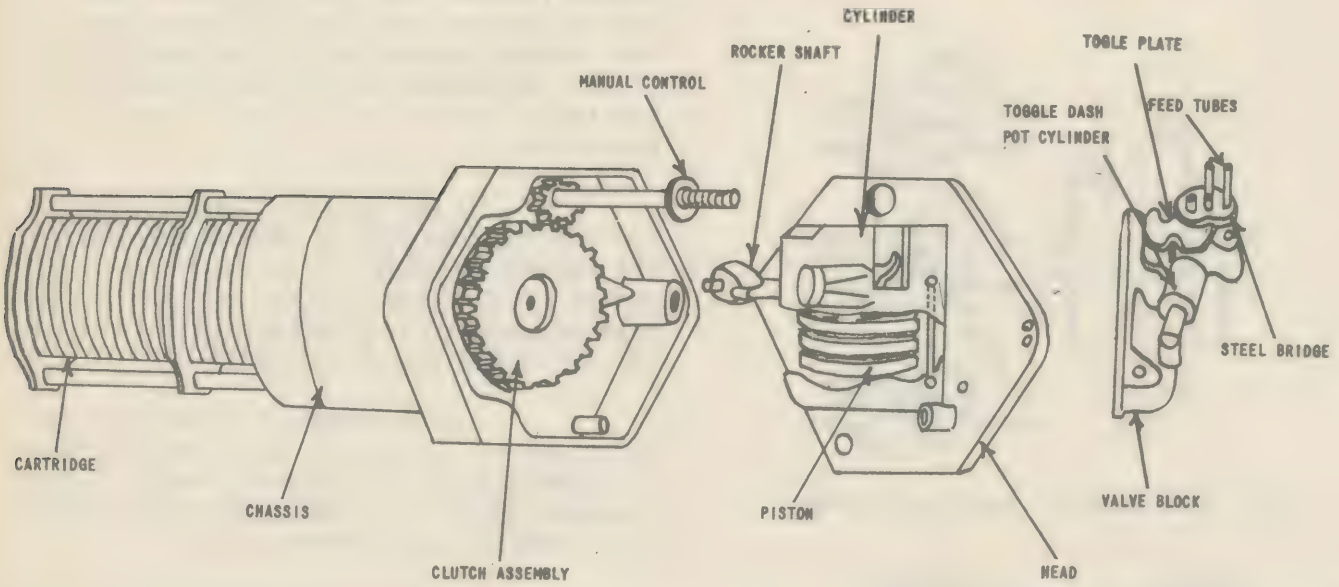


Fig. 139. Hydromatic Cuno Oil Filter.

If it has turned, the Cuno is operating; if it appears not to have turned, re-check because it may have returned to its starting position. If the check indicates that the Cuno is not functioning properly, mark defective and return for overhaul.

(h) This check should be made at least once every ten (10) hours.

(i) Ordinarily the speed of the piston will vary directly with the oil pressure the pump produces and inversely with the viscosity of the oil.

(j) Provisions must be made for the exhaust oil to return to some low pressure area such as the crankcase.

(k) On filters equipped with the "Auxiliary Manual Turning Device" a gear is placed on the clutch center which engages a pinion carried on a jack shaft extending through the cover plate of the motor. This permits manual turning of the element from the outside.

(l) All built-in cuno filters are provided with an offset mounting stud hole to prevent their being installed in an incorrect position. If a filter does not appear to fit its mounting pad, check with the engine manufacturer's installation drawings to determine the correct relationship of parts.

2. OILING SYSTEM.--*a. General.*

(1) Although the complete oiling-system of an aircraft power plant includes the lubrication system of the engine, only the external units of the system are shown in oiling-system diagrams of specific types of aircraft. For that reason this section deals only with the external units of the system. The internal engine lubrication system is treated separately under another heading.

(2) The oiling-system performs two functions. It provides for an adequate oil supply, the amount determined by the fuel system capacity, and it incorporates a means of cooling the hot oil discharges from the engine. It is designed and located in the aircraft to furnish oil by gravity to the inlet side of the engine pressure pump during practically all positions of flight except inverted.

b. Oiling-System Units.-- (1) The major units in an oiling-system include the supply tank, the necessary piping and connections, the oil temperature regulator assembly, the oil temperature gage, and the oil pressure gage. Some modern oil systems also incorporate an oil dilution system.

(2) **Supply Tank.**--The tanks are usually constructed of aluminum, aluminum alloy, or stainless steel and are of such

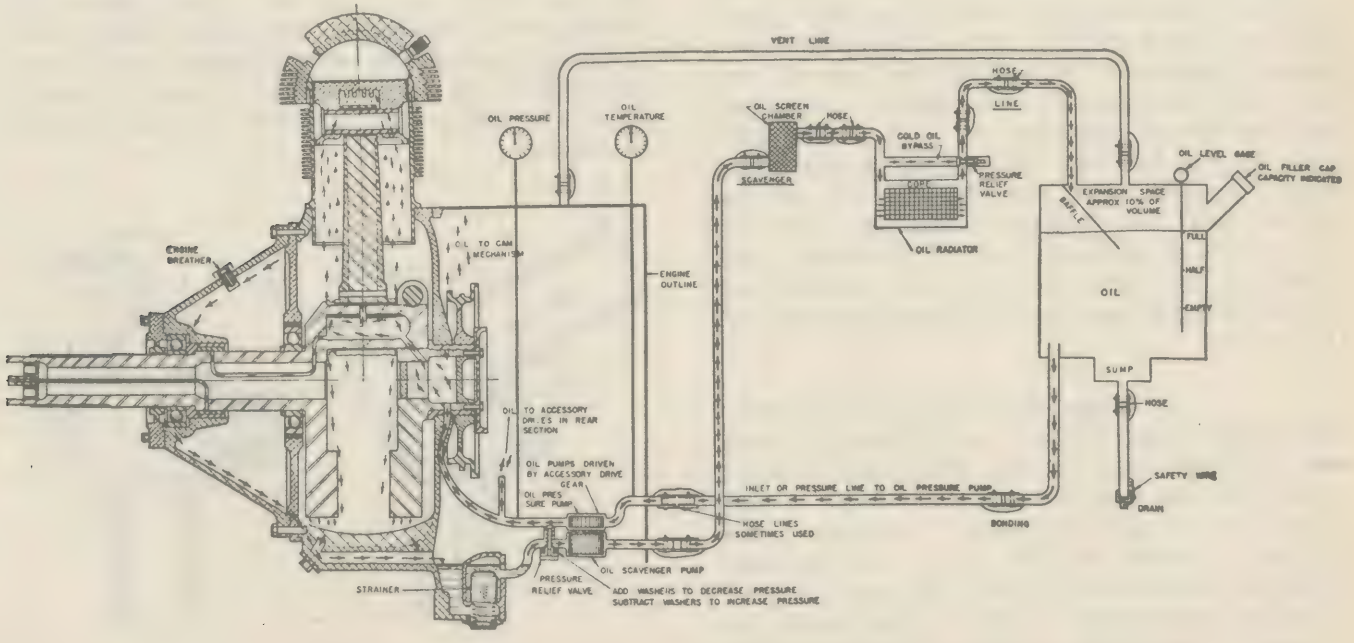


Fig. 140. Schematic Layout of Complete Dry Pump Lubrication System.

design as to permit installation in the aircraft as close to the engine as possible. The ideal tank location is on the engine side of the fire wall with its center approximately 20 inches above the engine oil pump when the aircraft is in its ground position. Oil tank capacity should provide for one gallon of oil for each eleven gallons of fuel for air-cooled engine installations, and one gallon of oil for each fourteen gallons of fuel for liquid-cooled engines. These figures do not include the oil in the piping, regulator, and engine, which usually totals from one to three gallons.

(3) The tank outlet is usually located in its lowest section in order to permit complete drainage while the aircraft is in ground position or in normal flight attitude. The outlet is so arranged that with the tank filled to one-half its normal capacity, it will not be uncovered in any normal flight attitude. The tank inlet line from the oil regulator enters the top of the tank and is of the same size as the outlet line. The two vent outlets lead from the top of the tank to the engine crankcase. The filler and cap unit are conveniently located for servicing and checking the oil supply in the tank.

(4) The supply tank used in conjunction with an oil dilution system incorporates a hopper or metal tube installed inside the tank in a vertical position, with the top of the hopper approximately one-half inch from the top of the tank and the base of the hopper extending down inside of the sump to within one-half inch of the bottom. The minimum oil flow area from the tank into the bottom of the hopper must be greater than the area of the oil tank outlet line. The hopper has a volume of from one to two gallons of oil, depending on the oil flow capacity of the engine.

(5) **Tube Fittings, Oil Lines, and Drain Cocks.**--There are comparatively few fittings used in the plumbing of aircraft oiling systems. Other than a few street-ells and oil-gage fittings, the system is made up of large piping and flexible hose connections. The supply tank is usually secured to the engine mount in a more or less rigid frame. It necessarily follows that there is vibration, which is violent at times, between the fixed oil system units and the engine. This vibration naturally concentrated in the oil system tubing and is conducive to fatigue failure in piping. This effect is considerably reduced by the use of flexible hose connections.

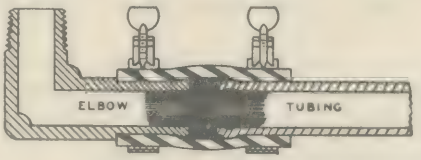


Fig. 141. Flexible Oil Hose Connection.

(6) **Rubber hose is used in the flexible connections** and is clamped to the tubing or fittings with standard hose clamps. The length of the hose exposed to the oil flow should not be greater than the inside diameter of the hose. (See fig. 141.) Each hose connection used on the oil line connecting the scavenging pump outlet to the oil cooler is secured by four standard hose clamps because of high pressure exerted by the flow of cold oil when the engine is first started.

(7) **Piping may be of copper or aluminum tubing.**--The wall thickness of copper tubing should not be less than 0.040 inches and of aluminum tubing not less than 0.050 inches. The ends of oil pipes are raised to insure a more positive attachment of the hose connections. Avoidance of excessively tightened hose clamps insures a properly installed flexible hose connection. Oil lines are painted with a band of yellow paint near each end for identification purposes.

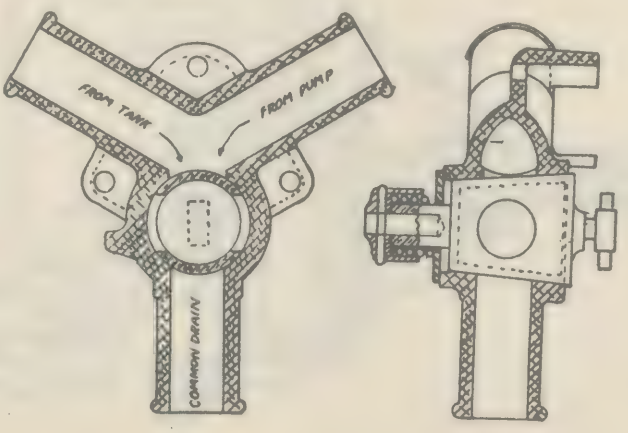


Fig. 142. Oil System Drain Cock.

(8) **A drain cock** (fig. 142) is installed to drain the system. One inlet of the cock is from the tank and the other from the engine pump, both draining into a common outlet. The cock is manually controlled by rotating a handle from the vertical position, which opens the cock, to the horizontal position, which closes it. When closed, the cock handle is locked in position to prevent movement. In an oil dilution system, an auxiliary valve is incorporated in the drain cock to provide a means of mixing a certain quantity of fuel with the oil.

(9) **Oil Temperature Regulator.**- There are a number of sizes of oil temperature regulators in service to control the operating temperature of the oil. The operating temperatures must be kept within certain limits to control viscosity for proper lubrication. The oil temperature regulator, commonly known as the oil cooler, is placed in the oil system between the oil outlet of the engine and the oil inlet of the supply tank. It consists of a built-up core section surrounded by a metal jacket. A thermostatically controlled valve is incorporated in the unit to control the flow of oil automatically either through the core or around the shell, depending upon the temperature of the oil. The oil is cooled by the air moving through the core tubes while the oil passes around the tubes. Oil coolers are usually cylindrical in shape and are so designed that the relief valve assembly regulates the amount of oil forced through it to the supply tank. Various diameters of different core areas are used, depending upon the amount of oil circulated through the particular engine installation.

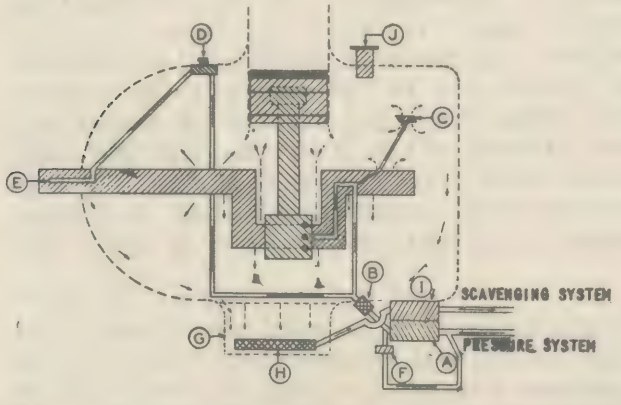


Fig. 143. Oil Temperature Regulator with Thermostatic Valve Closed.

(10) **A Thermostatically Operated Valve** is incorporated in oil temperature regulators to control the passage of oil automatically through the cooler. When the oil scavenged from the engine is comparatively cool, the thermostatic valve is open, permitting the oil to flow around the core jacket to the top of the supply tank without flowing through the core. When the oil reaches a normal temperature, the thermostatic valve (fig. 143) closes and directs the oil through the core for cooling purposes. Although it is possible to vary the operating temperature of the oil slightly by incorporating a number of gaskets in the thermostatic regulator valve assembly, it must be assumed that these valves are nonadjustable. They are usually designed to operate and shunt the oil through the cooler when the oil reaches a temperature of approximately 60° C. A thermometer bulb is installed in a well incorporated in the inlet line from the supply tank to the engine pump. It registers the inlet oil temperature on the temperature gage in the aircraft cockpit.

(11) Where a shutter assembly is installed in the air exit side of the regulator core, it may be operated to maintain desired oil temperatures. Where there is no provision for a shutter assembly, it is permissible in cold weather to blanket the core area partially with fibreboard or other suitable material in order to obtain proper oil temperatures.

(12) **Pressure Gage.**--The oil pressure gage in the aircraft cockpit is connected to the pressure line of the lubrication system in the engine. A restricted orifice is placed in the oil pressure gage line at the engine end. The gage line may be filled with instrument oil in cold weather, giving a comparatively rapid and true indication of oil pressure during engine warm-up.

c. Typical Aircraft-Oiling System.- (1) By referring to the oiling system diagram (fig. 144), a general idea of the circulation of the oil to and from the engine may be obtained. Assuming that the supply tank has been serviced to its proper level, the oil flows by gravity through large tubing to the inlet side of the engine-oil pressure pump, which forces the oil under pressure through the internal

lubricating system. The engine scavenging pumps return the oil from the engine-oil sumps to the top of the supply tank through the oil-temperature regulator. In most instances the crankcase is vented through suitable piping to the top of the supply tank. Two vent lines are used and are located so that at least one vent is open in all normal flight attitudes.

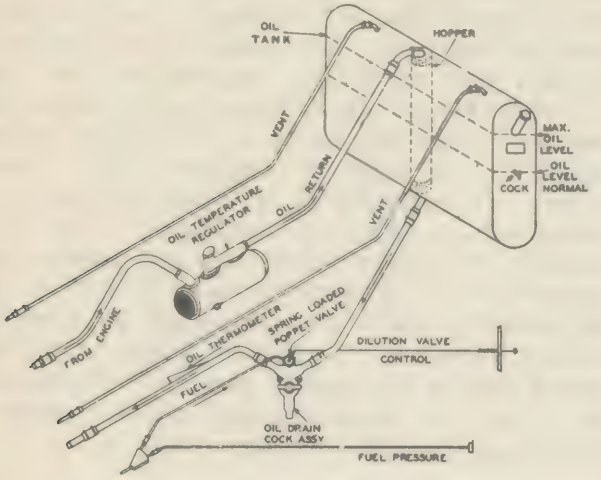


Fig. 144. Typical Aircraft-Oiling System.

(2) The thermometer well, for the installation of the thermometer bulb, is incorporated at a tangent in the oil piping between the outlet of the tank and the engine oil pressure pump; therefore, the indicator gives a temperature reading of oil entering the engine. The reading obtained at this point is more valuable than one taken from some other point in the oil return line.

(3) The drain valve is also located in the tank to engine pressure pump piping at the lowest point to permit complete drainage of the tank and engine. It should be noted that the drain cock does not drain the oil from the oil temperature regulator which must be drained separately by removing the plug located at the lowest point on the assembly.

d. Oil Dilution System.--(1) Due to difficulties experienced in starting aircraft engines in cold weather, an oil-dilution system has been developed to dilute the oil immediately before the engine is stopped when a cold start is anticipated. Inasmuch as the high cranking torque of a cold engine is due to the high viscous drag of the oil, particularly between the pistons and cylinder walls, it is evident that a decided thinning of this oil immediately before the engine is stopped will greatly reduce the cranking torque and facilitate subsequent starting.

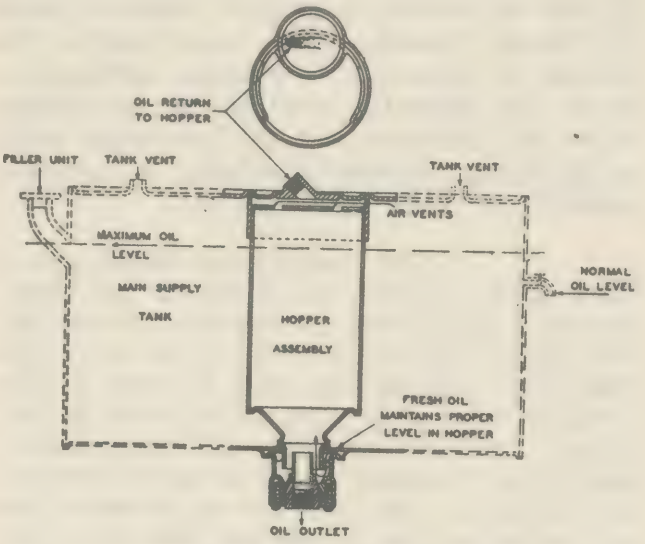
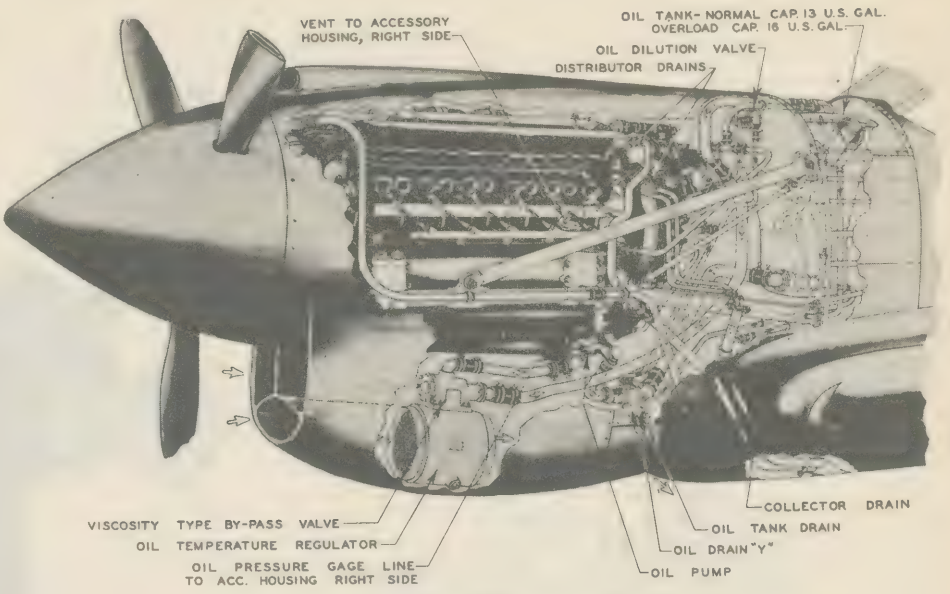


Fig. 145. Typical Hopper Tank.

(2) In fig. 145, the units comprising the oil-dilution system are shown, and with the exception of the hopper in the supply tank, may be readily incorporated in any aircraft oiling system. A line is connected from the fuel pressure line to a special Y drain cock in which a spring-loaded poppet valve is installed. This valve is operated manually from the cockpit, and before the engine is stopped in cold weather, a small amount of fuel is allowed to enter the oil-in line at this point by holding the dilution control open for a short time with the engine operating. This operation permits the diluted oil to replace the heavy oil throughout the entire engine, thereby facilitating starting in cold weather. Inasmuch as some of the diluted oil is returned to the hopper in the supply tank during the last minutes of operation, this diluted oil will be the first oil used at the next start, thereby insuring a more positive flow to the engine pump. A typical hopper installation is shown in fig. 145.

(a) Because use of the oil-dilution system increases the combustible vapor in the discharge from the engine crankcase breather, a pipe is installed to conduct these vapors from the breather to the cowl line.

(b) With oil dilution, there is a tendency for the diluted oil from the tank to seep into the engine crankcase and into the cylinders when the engine is at rest. The only satisfactory solution to this problem is the use of a check valve installation in the strainer assembly in the engine. This valve is spring loaded so that the normal gravity pressure of the oil cannot cause seepage into the engine; however, it opens readily under the influence of pump pressure when the engine is in operation


VENT TO ACCESSORY HOUSING, RIGHT SIDE
OIL TANK- NORMAL CAP. 13 U.S. GAL. OVERLOAD CAP. 16 U.S. GAL.
OIL DILUTION VALVE
DISTRIBUTOR DRAINS
COLLECTOR DRAIN
OIL TANK DRAIN
OIL DRAIN "Y"
OIL PUMP
VISCOSITY TYPE BY-PASS VALVE
OIL TEMPERATURE REGULATOR
OIL PRESSURE GAGE LINE TO ACC. HOUSING RIGHT SIDE

Aircraft Lubrication System

Fig. 145A

e. *Operating Instructions.*--(1) When servicing an oil tank, no attempt should be made to fill the tank completely since a definite air space must be provided to accommodate expansion. In most tanks, the filler cap is so located that the correct level is automatically established. In some tanks a level cock is also provided to permit an accurate check of the filling operation.

(2) **During engine warm-up on the ground it is most important to check carefully the operation of the lubrication system.** When an engine is first started, the oil pressure reading will generally be very high due to the high oil viscosity. However, even at high pressures the rate of oil circulation may be quite low, so extreme care is necessary to prevent engine wear. In general, the engine r.p.m. should be kept low until a rise is observed in oil temperature, indicating proper circulation. Take-off can be safely accomplished after only a moderate period of ground operation, provided the oil pressure indication is steady and within the proper range, and the engine is otherwise satisfactory. Unusually quick take-off is possible with airplanes having oil dilution systems. Prolonged periods of ground operation are definitely harmful to most high output aircraft engines.

f. Maintenance.--The principal points to be checked in the maintenance or oiling systems may be enumerated as follows:

(1) The tank should be inspected for proper mounting and for signs of leaks and dents.

(2) The oil-temperature regulator supports should be checked and the core inspected for restrictions.

(3) The oil-dilution valve linkage will sometimes bind and fail to operate properly unless carefully adjusted.

(4) The oil tubing must be properly installed and supported, the hose connections must be in good condition, and the clamps should be tested for tightness.

(5) Screens and filters accumulate a large amount of dirt and sludge and are, therefore, cleaned periodically.

(6) All plugs and drains must be carefully checked for leakage and for proper safetying.

Section IV
ENGINE OPERATION

1. STARTING SYSTEM.--*a. Types.*--The majority of aircraft engines are equipped with starter systems to provide a means for starting the engines without resorting to hand cranking. The common types are:

(1) Hand inertia starters
(2) Combination hand and electric inertia starters
(3) Direct cranking
(4) Cartridge starters
(5) Hand turning gear starters
(6) Air injection starters.

b. Hand Inertia Starter and Eclipse Aviation Engine Starter.

(1) General Description.--The starter is of the concentric, inertia type. Operation depends upon the storage of energy in a fly-wheel which is brought up to a high speed by manual operation of the hand crank. The high speed is attained through multiple gearing. The stored energy is then expended at the will of the operator in cranking the engine. Included in the mechanism is a torque-overload release, which prevents abnormal stresses in the mechanism if the engine should back-kick while cranking.

(2) Detailed Description.--(a) The operation cycle of the starter is as follows: The drive from the hand crank is through a pair of bevel gears, revolving the driving barrel, on which are mounted the planetary pinions. These roll within the fixed internal gear, and the rotation of the planetary pinions imparts motion to the sun pinion with which they are in mesh. The sun pinion and sun internal gear are integral, the latter driving the spur pinion which is integral with the spur bell gear. The spur bell gear rotates the fly-wheel pinion thereby accelerating the fly-wheel. Through this gear train the fly-wheel is brought up to a normal speed of about 12,000 r.p.m.

(b) The stored energy is transmitted from the fly-wheel in the inverse direction to driving barrel, through the torque-overload release which is in the form of a multiple disc clutch under adjustable spring pressure and to an internally threaded by-member within which is threaded a longitudinally slidable screw shaft splined to the starter driving jaw at its outer end.

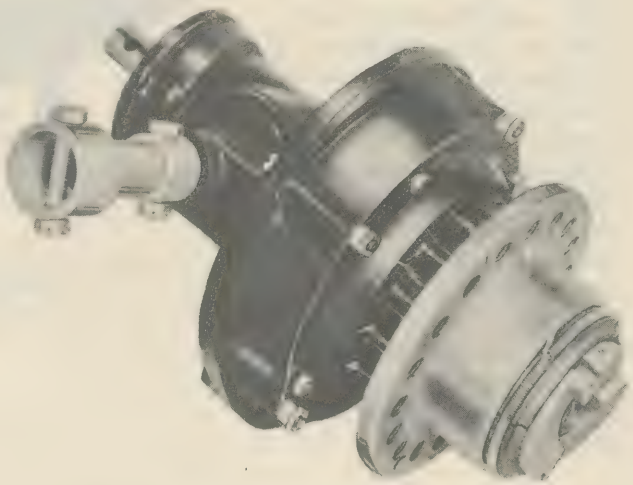


Fig. 146. Typical Hand Inertia Starter.

(c) The meshing jaw is advanced through the medium of a compression spring and may be withdrawn by direct pull from the operating rod if for any reason the engine does not start and comes to rest with the jaws in mesh.

(d) When the engine starts, the rotation of the crankshaft jaw is faster than the starter jaw and the latter is automatically disengaged.

(e) All bearings are of the ball type and are standard except for those mounting the driving barrel. These are of the built-up cone type, and adjustment is provided for assembly purposes. Sixty (60) best quality steel balls are used at each end.

(3) Application of Starter.--(a) To apply this starter to the engine, remove the starter plate cover and examine the engine starter jaw to make certain that the engine jaw is of proper rotation and that it mates with the corresponding jaw on the starter.

(b) Before proceeding further, be definitely certain that the outermost point of the engine jaw is 1-11/16" from the rear case flange. There should be approximately 3/32" clearance between the engine jaw and starter jaw when the latter is out of mesh. This should always be checked when making an application.

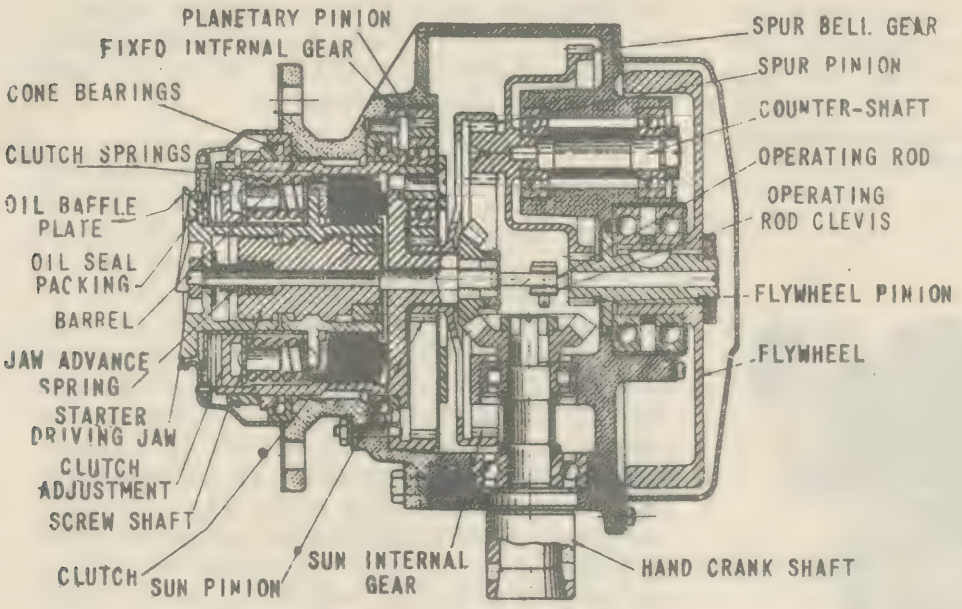


Fig. 147. Sectional View of Hand Inertia Starter.

(4) **Operating Rod.**--The Starter is meshed by means of an operating rod extending from the starter, at the protruding end of which is keyed a lever with two arms at right angles. This provides for connecting an operating linkage running either to the side of the fuselage, to the cockpit, or to both as is desired. This lever may be adjusted to any 90° position required.

(5) **Operation.**--(a) To start the engine, put the crank in place. Inspect the operating rod and make certain that the rod is in the disengaged position, making sure that the jaws are not meshed. Revolve the crank handle in proper direction of rotation. Best results are obtained by starting the cranking operation rather slowly without exerting any great force until an appreciable speed is attained, then exerting greater pressure on the crank handle as the speed increases.

(b) Efficient starting results are obtained at a maximum crank handle speed of 75 to 80 r.p.m. When maximum speed is reached, turn on the ignition switch and pull the operating rod. It will be found that the use of a booster magneto is in most cases not necessary, but if used, it will naturally facilitate starting, particularly in cold weather.

(c) When the engine starts, no further attention to the starter is necessary, the disengagement being automatic. If, however, the engine fails to start, push on the operating rod to insure disengagement of the drive and repeat the operations outlined above.

(d) In case disengagement of the jaws is not readily accomplished by manipulating the operating rod or whenever flexible enclosed cable installations prevent the jaws from being disengaged as mentioned previously, it is suggested that the methods below be followed:

(e) Turn the propeller by hand (ignition "off") about 1/3 of a revolution in its normal direction. This disengages the engine from the starter at once.

(f) Turn the propeller opposite its normal direction for about 1/3 turn. This causes the starter fly-wheel to revolve in the reverse direction and after about 1/2 minute the fly-wheel will cause the jaws to demesh.

CAUTION

At no time should the starter be cranked with the jaws engaged as this imposes a severe strain upon the starter mechanism and damage may result.

c. Combination Hand and Electric Inertia Starter.--(1) The hand inertia starter can be operated by an electric motor mounted on the fly-wheel housing. To actuate this starter by electricity, a solenoid starting switch and also a solenoid meshing device are mounted on the motor housing flange. A double contact push-pull switch is mounted in the cockpit to operate the solenoids.

(2) A booster coil is mounted in a convenient place and is connected on the positive side of the meshing device circuit. It will furnish a high tension current to the distributor booster segment in the magneto when the meshing solenoid is put into operation.

Fig. 148. Combination Hand Operated and Electric Inertia Starter with Solenoid Starting Relay.

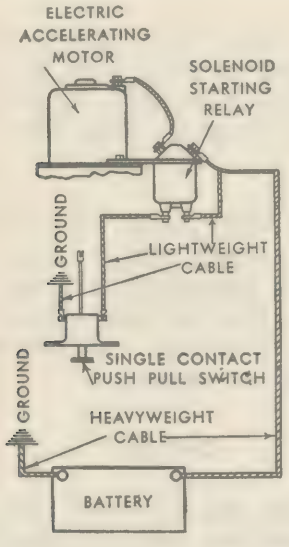


Fig. 149. Typical Single-Wire (Grounded) Diagram for Combination Hand and Electric Inertia Starter--Manual Engagement..

d. Direct Cranking Type Starter. (1) The direct cranking type starter is a combination unit for hand or electrical operation, and provides instantaneous and continuous cranking of the engine. It consists basically of an electric motor, a gear reduction, and an automatic engaging and disengaging mechanism which operates through on adjustable torque-overload release. As the engine is cranked directly by the starter, there is no preliminary storing of energy required as in the case of the inertia type starter.

(2) For electrical operation, the starting switch is closed and the battery energy is applied across the motor terminal. The torque of the motor is transmitted through a gear reduction to the adjustable torque-overload release mechanism. This in turn, actuates a splined screw shaft which moves the starter jaw anially outward to engage with the engine cranking jaw before it begins to rotate. Thus, complete engagement is accomplished before cranking begins. The torque-overload release mechanism consists of a multiple disc clutch adjusted to a predetermined value to deliver a sufficient, yet not excessive, cranking torque to the engine. In case of engine kick-back, the clutch slips, preventing damage to the engine or starter. When the engine starts, the starter automatically disengages from the engine.

e. Cartridge Starter (Shotgun) Type.--(1) A cartridge, which closely resembles an ordinary shotgun shell except for size, is placed in the breech (size depending on the engine). The cartridge is placed and locked. The position of the opening lever in the housing is down against the stop. The engine is primed in the usual manner. The engine ignition switch is turned on and the starter switch operated. When the circuit is closed, the cartridge is set off. The powder begins to expand in the breech forcing the unburned portion of the charge through the intake tube and into the combustion chamber of the starter which completes combustion.

(2) The burning of the powder produces a gas which expands with the heat of combustion. The action is identical with that which takes place in a shotgun when the trigger is pulled. The pressure caused by this expansion in the combustion chamber acts on the head of a piston in the starter, pushing it down. As the piston moves down, it causes the clutch jaw of the starter to engage with the engine clutch jaw. After engagement, the piston is caused to rotate by helical splines or threads with a very high lead. This

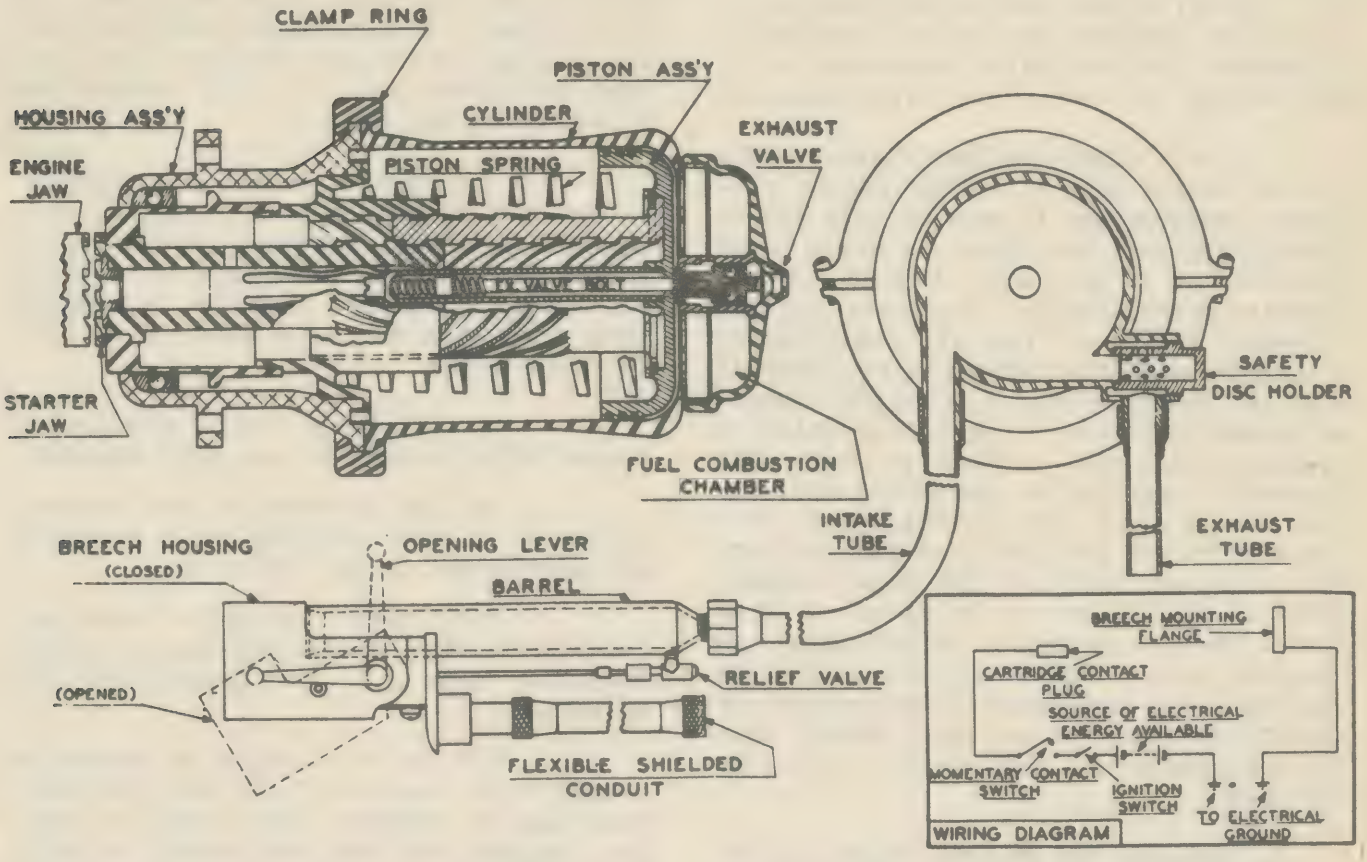


Fig. 150. Sectional View of Cartridge Type Starter.

rotation of the piston causes the engine crankshaft to rotate at a speed adequate for starting.

(3) After the piston has completed its stroke and turned the crankshaft, the exhaust valve in the combustion chamber of the starter opens and the burned gas passes out through the exhaust tube. At the same time, the clutch jaw of the starter is automatically disengaged from the engine and the piston is returned to its original position by a coil spring. As the piston moves back, the exhaust valve closes. If the engine is damaged so that it will not turn, if there is unburned carbon in the combustion chamber when the new cartridge is discharged, or if for any other reason the pressure inside the combustion chamber exceeds that which has been established as safe, a safety disc in the combustion chamber is ruptured and the pressure is allowed to escape. When this occurs, a new safety disc must be installed before the starter can be used again.

Fig. 151. Combustion Starter.

f. Hand Turning Gear Type Starter.--The hand turning gear type starter is used on low horsepower engines and on installation where an electrical source of power is not available. This starter consists of a gear reduction unit which operates an automatic engaging and disengaging mechanism through an adjustable torque-overload release. Mechanical features are incorporated to safeguard both the operator and starter from injury in case of engine kick-back. In the event of kick-back, the torque-overload release automatically disconnects the starter from the engine, thus

preventing damage to the starter mechanism. As a further protection to the operator, a ratchet is provided on the hand crankshaft to prevent the possible transmission of any reverse motion to the crank handle.

g. Air Injection Type Starter.--This type of starter operates from engine generated pressure and is particularly adaptable to application where an electrical installation is not suitable and hand-cranking is undesirable. The system includes a compact engine-driven air compressor; a timed rotating distributor valve, integral with the compressor; a storage tank; an automatic pressure regulating valve; a pressure gage; and a fuel primer. The starter is operated by the air pressure in the storage tank. The release of this pressure is controlled from the cockpit and is transmitted by the distributor valve to the cylinders in proper firing order. The air pressure dissipated in starting is rapidly replenished by the engine-driven compressor. Provisions are made to introduce a priming charge into the distributor as the starter is being operated.

2. HANDLING THE ENGINE.--The life of the airplane engine and its dependability rests upon the care which it receives, both in the air and on the ground. Care on the ground includes care in starting, stopping, use in taxying, and routine maintenance. Care in the air includes care in handling the engine during the take-off, while in the air, and during landing. When an emergency, or what appears to be an emergency, occurs, the safety of the personnel involved is primary; equipment is secondary.

a. Starting an Aircraft Engine.
(1) Starting an aircraft engine should not be difficult except in extremely cold weather if proper procedure is followed in setting controls and in the use of the primer and starter. If a plane is permitted to stand for a considerable length of time, as during storage, the lower cylinders of a radial engine may accumulate oil. If an attempt to start the engine is made when there is an over-supply of oil in the combustion chamber, a tremendous hydraulic pressure is produced, a pressure sufficient to cause serious damage to pistons and connecting rods. For this reason, the engine should always be turned over by hand before the first start each day. If it is stored for any length of time, the spark plugs should be removed from the lower cylinders and the oil should be permitted to drain out.

(2) On the majority of carburetors, the mixture control is set at full rich for starting; however, on Stromberg Injection Carburetors they are set in idle cut-off position. The throttle is cracked about one-tenth open or a position to give 1000-1200 r.p.m.

(3) Cowling flaps should be opened fully except in very cold weather.

(4) The carburetor heat control should be in cold position or a backfire in starting may damage the valve.

(5) Controllable or constant speed propellers should be placed in the low pitch (high r.p.m.) position for starting.

(6) The fuel valve is turned on a tank which contains fuel and the hand fuel pump is operated slowly until a pressure between four and six pounds is built up. (Instructions for Stromberg Injection Carburetors recommend a pressure of ten pounds or more.)

b. Handling a Hot Engine.--(1) Great care should be exercised in handling the propeller on a hot engine. Incandescent particles of carbon in the engine or highly heated engine parts may cause preignition and injury to personnel.

(2) If trouble is experienced in starting any engine due to "loading" or flooding, open the throttle wide and turn the propeller in the ***normal direction of rotation*** four to five revolutions. Afterwards, the engine can usually be started in the normal manner. When a propeller is turned backward on an engine equipped with a starter, the starter may "hang" and be damaged. A hot engine is flooded very easily.

c. Engine Stopping.--(1) Stopping the automobile engine requires the turning off of the ignition switch only. This is not always a satisfactory method for stopping an aircraft engine. Various methods

are employed. Manufacturers specify the proper method to use in stopping their engines and these instructions should be followed. The general procedure outlined below will reduce time in stopping, will reduce backfiring, and will also prevent overheating of tightly baffled, air-cooled engines.

(2) The following procedure applies to airplanes equipped with brakes and force feed fuel systems, low power output engines which are not in the habit of after-firing when the ignition switch is cut off, and engines not equipped with carburetor idle cut-off features or fuel injectors.

(a) Set the mixture control at full rich.

(b) Close the fuel valve.

(c) Close throttle to normal idling position and allow engine to run at normal idling speed for a few minutes with the cowling flaps or radiator shutters fully opened until fuel pressure has dropped to zero.

(d) Open throttle slowly until engine reaches a speed of from 800 to 1000 r.p.m. and cut the ignition switch. As the propeller slows down and with the ignition switch off, slowly move the throttle to full open position.

(e)) When the engine has stopped, turn fuel valve to the "on" position and operate the hand fuel pump until an indication of pressure is shown on the fuel pressure gage. This insures that the carburetor and fuel lines are filled with fuel in preparation for the next starting.

(f) Allow throttle to remain in its open position after stopping the engine as this reduces the likelihood of accidental starting while the engine is hot.

(3) On airplanes not equipped with brakes, it is permissible to cut the ignition switch at normal idling speed instead of at 800 to 1000 r.p.m. Otherwise, the procedure is as outlined above.

(4) On airplanes equipped with gravity fuel-feed systems (having no fuel pressure gage to consult), it is permissible to stop the engine by cutting the switch after it has been run at idling speed for a few minutes.

(5) When a high performance engine constantly "afterfires" when stopped by cutting the ignition switch, it is best to operate the engine at 800 to 1000 r.p.m. with the fuel valve closed until the fuel supply is exhausted before cutting the switch. On engines such as these, it may be necessary to idle at a higher than normal idling speed in order to prevent the engine from overheating and fouling the spark plugs. The idling period should not be prolonged.

d. Idle Cut-Off Stopping.--Engines equipped with carburetors having idle cut-off are stopped without closing the fuel valves by idling at 600 to 800 r.p.m. and then setting the mixture control lever to idle-cut-off position (full-lean). This actuates the idle cut-off valve which causes the engine to cut out rather abruptly. The ignition switch is turned to the "off" position after the engine stops firing. Since the carburetor is not drained, the mixture control lever will be left in the full-lean position after the engine stops firing as a precaution against accidental starting. In stopping these engines, the throttle should not be opened because this will force a charge of fuel into the engine.

e. The Take Off.--(1) Sudden opening and closing of the throttle on an airplane engine should be avoided except in case of emergency. On the take-off the throttle should be gradually but quickly opened. It should never be "kicked" or "jammed" open.

(2) All engine instruments and controls should be carefully examined before the take-off, and readings and settings should be correct. After sufficient altitude has been gained, the engine controls should be set for cruising speed, and all engine instruments should show correct readings.

(3) Some common mistakes in handling the engine on the take-off are: Improper adjustment of engine controls,

such as the altitude and spark controls; fuel supply from the reserve tank; rough handling of the throttle; and closed radiator shutters.

(4) Engine instruments should be examined frequently during flight. Water and oil temperatures, and oil and fuel pressures should be constant and correct at cruising speed. An airplane engine will run better and last longer if it is run at a moderate speed while cruising. The increase in engine speed necessary to obtain a given increase in flying speed above normal cruising speed is very much greater proportionally than the increase in air speed obtained, and the fuel consumption becomes excessive. It can be seen that there is no advantage in running an airplane engine wide open in flight except in case of emergency, or where a certain maneuver requires excess power.

f. Landing and Taxying.--(1) While gliding in for a landing, it is best for the engine to keep it turning up at a speed just below that at which thrust commences to be exerted upon the airplane. If the engine cools excessively during the glide, the shutters should be closed sufficiently to keep the temperature normal. These precautions prevent "loading" and fouling of the engine, and unequal cooling of the parts, especially the valves and cylinder walls.

(2) An engine should be slowed down or idled from a high speed by gradual use of the throttle. The throttle should ***never*** be ***suddenly*** closed or opened except in case of emergency.

(3) Taxying should be accomplished by gradual use of the throttle also, with sudden fluctuations of engine speed reduced to an absolute minimum. It should never be accomplished by sudden short and strong bursts of engine speed, unless wind or ground conditions, or an emergency, make such action necessary.

g. Routine Maintenance.--(1) Like all complicated machines the airplane engine must be kept clean and well lubricated and parts and accessories must be maintained in proper adjustment. A badly adjusted, dirty, or poorly lubricated part or accessory is often the cause of engine trouble.

(2) Lubrication is one of the most important, if not the most important factor in airplane engine operation. The lubricating system should be maintained in such adjustment that all rubbing surfaces are thoroughly lubricated at all times and under all conditions of operation. None but the best oils of the correct grade should be used, and oil should be drained from the reservoir or tank as soon as it reaches such a condition that its lubricating qualities commence to become impaired. The average life of lubricating oil used in an airplane engine varies with the engine and with the grade and quality of oil being used.

(3) The exterior of the engine should be kept free from dirt and excess oil. Cleaning may be accomplished with rags, paint brushes, or air sprays, using kerosene or old gasoline as a solvent. When using gasoline as a solvent it is necessary to observe the utmost caution to prevent fire. All polished or unprotected exterior steel parts should be given a light coat of thin oil after cleaning to prevent rust.

(4) As long as a part or accessory is functioning properly it should be left alone, except for periodical cleaning and checking of adjustment. Adjustment of parts or accessories should never be attempted by inexperienced personnel. If trouble is experienced due to what is believed to be a poorly adjusted part or accessory, it is best in the long run to wait for someone experienced in airplane engine maintenance to remedy the trouble. "Monkeying" by the novice usually results in troubles more serious than the original one.

h. Operating Instructions for Engines with Injection Carburetor. (1) Introduction.--(a) The Stromberg Injection Carburetor is entirely different from previous types of carburetors in that it does not have a vented float chamber, but instead, has a closed fuel system from fuel pump to discharge nozzle. Fuel is prevented from leaking into the engine by the spring-controlled needle valve in the discharge nozzle which is closed when the nozzle fuel pressure is less than four pounds per square inch. Even though the fuel pressure is over four pounds (with throttle closed and engine standing still)

the fuel can flow only at the lowest idling rate. When the idle cut-off is in use it reduces the flow to considerably less than the idle flow. Since this is a closed system, it remains full when the engine is stopped by cutting off the fuel flow with the idle cut-off. Stopping the engine by shutting off fuel tank valve may allow vapor to be pumped into regulator and is not recommended.

(b) The procedure in the following paragraphs should be used for filling, starting and stopping engines equipped with these carburetors.

(2) **Filling.**--(a) When carburetor is first used after installation, or has been drained, this procedure should be followed: Open tank fuel valve. Set mixture control at automatic rich and throttle half open. Operate wobble pump slowly to raise fuel pressure to 4 lbs. sq. in. Continue to operate wobble pump until a small amount of fuel runs from supercharger drain.

NOTE: A special condition exists when the carburetor is partly filled with air. The rate at which fuel may enter the second Regulator chamber and the Fuel Control Body is held to idling rate, causing the carburetor to fill slowly. Since there are no vents in the system beyond the second Regulator chamber, all included air must escape through the nozzles causing the engine to stop after being started. To eliminate this condition remove the vent plug from second chamber of Regulator and work wobble pump until fuel stands level with plug opening.

(b) Usual filling time for carburetor--one minute.

(3) **Starting.**--(a) **Engine Cold.** *1.* Use external primer 3 to 5 strokes or as experience dictates.

2. Set mixture control in idle cut-off position and throttle at position to give 1000-1200 r.p.m.

3. Raise fuel pressure slowly to 10 lbs. or more with wobble pump. Engage engine with switches on. As soon as engine starts move mixture control to automatic rich; continue to work wobble pump slowly to help engine build up pressure.

4. If engine does not start after 2 to 3 turns, prime by moving mixture control out of idle cut-off for approximately one-half turn of engine and then back to idle cut-off. When engine starts firing during this operation move mixture control to automatic rich position.

(b) *Engine Warm.--1.* Follow procedure for Cold Engine without using external primer.

2. Do not operate wobble pump excessively when mixture control is out of idle cut-off position as fuel is discharged into engine when mixture control is in any position except idle cut-off.

3. Operating the throttle DOES NOT discharge fuel into the engine. Engine can be started with throttle in any position. If engine becomes loaded up, place mixture control at idle cut-off, open throttle, and turn engine over with starter or by hand until clear.

4. Refer to Engine Manufacturer's Manual for other starting instructions.

(4) **Adjusting Idle.**--(a) The throttle position at closed throttle is controlled by an eccentric stop at the lower left-hand side of the throttle body. The stop is adjusted with a screw-driver and has notched positions which lock automatically. The idle mixture is adjusted by means of the knurled screw on the linkage on the lower left-hand side of the fuel control body. Adjustment is made by loosening the slotted head clamp screw on the pointed lever above the adjusting screw and turning knurled screw. Turning the knurled adjusting screw to the right gives a leaner mixture and to the left a richer mixture.

(b) In making an idle adjustment on an engine, the throttle stop should first be adjusted to give the approximate speed desired and the mixture then adjusted to give the desired operation. In making changes in the mixture adjustment, the slack should be turned out

STROMBERG INJECTION CARBURETOR

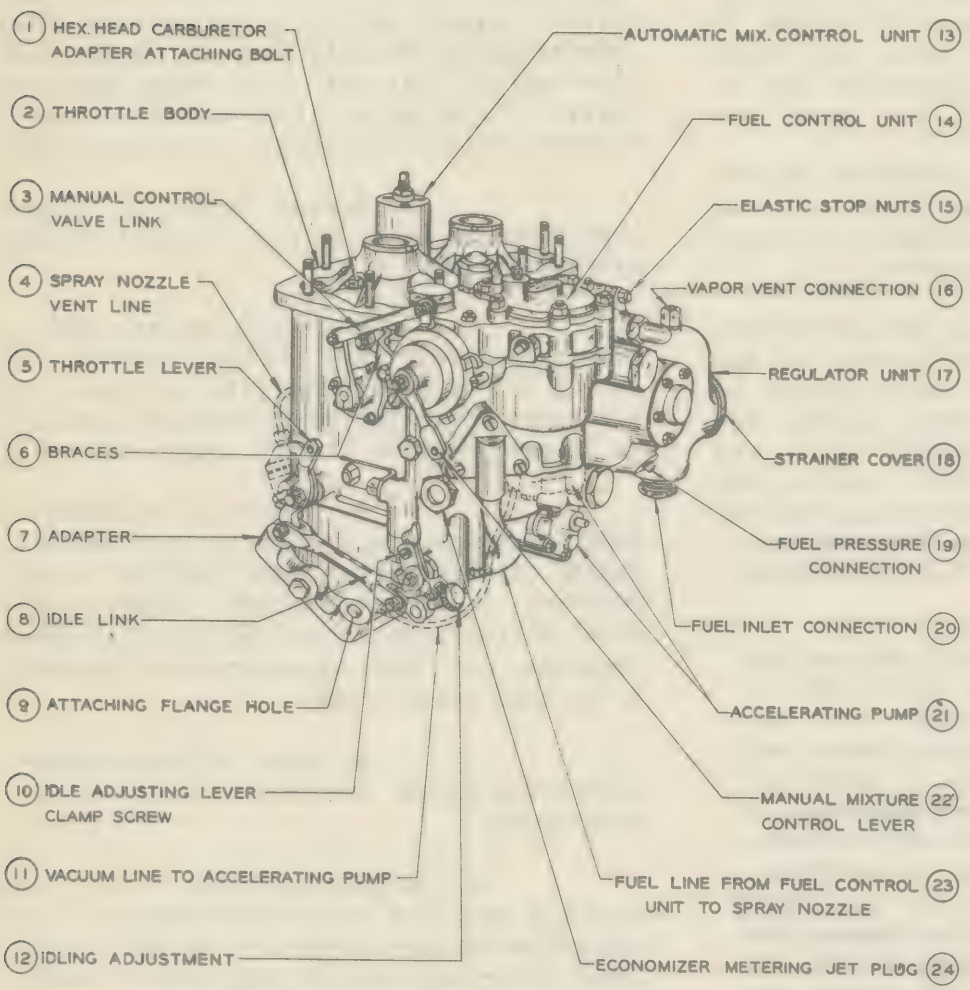

1 HEX. HEAD CARBURETOR ADAPTER ATTACHING BOLT
2 THROTTLE BODY
3 MANUAL CONTROL VALVE LINK
4 SPRAY NOZZLE VENT LINE
5 THROTTLE LEVER
6 BRACES
7 ADAPTER
8 IDLE LINK
9 ATTACHING FLANGE HOLE
10 IDLE ADJUSTING LEVER CLAMP SCREW
11 VACUUM LINE TO ACCELERATING PUMP
12 IDLING ADJUSTMENT
13 AUTOMATIC MIX. CONTROL UNIT
14 FUEL CONTROL UNIT
15 ELASTIC STOP NUTS
16 VAPOR VENT CONNECTION
17 REGULATOR UNIT
18 STRAINER COVER
19 FUEL PRESSURE CONNECTION
20 FUEL INLET CONNECTION
21 ACCELERATING PUMP
22 MANUAL MIXTURE CONTROL LEVER
23 FUEL LINE FROM FUEL CONTROL UNIT TO SPRAY NOZZLE
24 ECONOMIZER METERING JET PLUG

Fig. 152.

of the knurled screw before the clamp screw is loosened, then loosen clamp screw, turn adjustment as needed and lock. Open and close throttle and adjust throttle stop as necessary. The clamp screw should be tightened and the throttle opened and closed between each adjustment of the idle mixture screw. Do not make idle adjustments on cold engine.

(5) **Flight Operation.**--Normal operation with this carburetor is with the mixture control lever set at automatic rich. In this position the carburetor automatically compensates for changes in air temperature and pressure. When the mixture control is set at full rich the automatic mixture control is NOT in operation. Manual control of the mixture strength is obtained by setting the mixture control lever in the range between automatic rich and automatic lean. Engine should not be operated in automatic lean except on special instructions from the engine manufacturer.

(6) **Stopping Engine.** -To stop engine, move mixture control to idle cut-off position with engine turning about 800 r.p.m. and at same time open throttle. Turn off ignition. This will give a clean cut-off without after-firing. It should be noted that with this carburetor, moving the mixture control to idle cut-off will stop engine at any speed or throttle position. Fuel tank valves should be closed when engine is not being operated.

(7) **Feathering.**--Close throttle, move mixture control to idle cut-off, turn off fuel to engine, and feather propeller.

(8) **Unfeathering.**--Hold unfeather button on until tachometer shows at least 800 r.p.m., throttle cracked, mixture control in idle cut-off, turn fuel on. When fuel pressure shows 4 lb. or 5 lb. by engine windmilling, turn switch on, start engine, watching tachometer to make sure engine is running. Move mixture control up to automatic rich. If engine should backfire, work wobble pump to be sure that all the air is cleaned out of the carburetor.

3. TROUBLE SHOOTING.

a. Engine Fails to Start.

(1) Lack of gasoline
(2) Primed too much
(3) Insufficiently primed
(4) Throttle open too wide
(5) Faulty spark
(6) Lack of Compression
(7) Camshaft out of time
(8) Ignition out of time
(9) Cold motor.

b. Engine Stops.

(1) Lack of gasoline
(2) Faulty spark
(3) Overheated.

c. Lean Mixture.

(1) Water in carburetor
(2) Dirt in jets
(3) Poor gasoline supply
(4) Low gas level in carburetor
(5) Backfiring
(6) Air leak
(7) Jets too small
(8) Altitude adjustment open too much
(9) Venturi tube too large
(10) Low test gasoline.

d. Scattering Miss.

(1) Lean mixture
(2) Rich mixture
(3) Faulty spark
(4) Water in carburetor
(5) Air leak in intake manifold
(6) Intake valve holding open
(7) Valve spring weak.

e. Motor will not Develop Proper Speed.

(1) Mixture slightly too lean
(2) Mixture slightly too rich
(3) Camshaft set too late
(4) Ignition set too late
(5) Poor grade of oil
(6) Overheating
(7) Tight motor
(8) Venturi tube too small
(9) Insufficient throttle opening
(10) Excessive carbon
(11) Poor grade of gasoline
(12) Valves not opening far enough.

f. Missing Fire at High Speed on One Cylinder.

(1) Shorted spark plug
(2) Shorted distributor wire
(3) Shorted distributor block
(4) Spark plug gap too wide
(5) Weak exhaust valve springs
(6) Poor compression.

g. Missing Fire at Low Speed on One Cylinder.

(1) Shorted spark plug
(2) Spark plug gap too close
(3) Poor compression
(4) Shorted plug wire
(5) Shorted distributor block
(6) Air leak around intake valve stem
(7) Weak exhaust valve spring.

h. Causes of Excessive Carbon in Cylinders.

(1) Use of too much oil
(2) Bad piston rings
(3) Poor grade of cylinder oil
(4) Rich mixture
(5) Motor run a long while without cleaning
(6) Poorly fitted pistons.

i. Result of Excessive Carbon in Cylinders.

(1) Pre-ignition
(2) Overheating
(3) Knocking, due to carbon, in time will loosen bearings
(4) Motor will not develop speed.

j. Backfiring in Carburetor.

(1) Cold mixture
(2) Lean mixture
(3) Air leak in manifold or around intake valves
(4) Valve springs weak
(5) Distributor wires attached wrong
(6) Magneto timed wrong
(7) Exhaust valve not opening, or not far enough

(8) Camshaft set too early
(9) Rich mixture
(10) Overheating
(11) Carbon
(12) Low test gasoline
(13) Venturi tube too large
(14) Intake valve sticking.

k. How to Detect Mixture by Color of Exhaust.

(1) Long red and yellow flame indicates rich mixture
(2) Short irregular light blue flame indicates a lean mixture
(3) Black smoke indicates mixture entirely too rich
(4) Blue smoke, too much oil being used
(5) Quick blue flame without yellow tip, correct mixture.

l. Causes of Rich Mixture.

(1) Carburetor flooding, leaky float, level too high, jet gaskets bad, hole in carburetor casting, float valve not seating, dirt under seat
(2) Jets too large
(3) Air intake stopped up, or choke closed part way.

m. Loud Reporting Out of Exhaust.

(1) Pre-ignition
(2) Camshaft set too early
(3) Rich mixture
(4) Spark too late
(5) New or stiff motor
(6) Faulty spark.

n. Pre-ignition.

(1) Carbon
(2) Overheating
(3) Rich mixture
(4) Magneto out of time
(5) Wires from distributor crossed or led to wrong cylinder.

o. Faulty Spark.

(1) Breaker points not spaced properly
(2) Breaker points burned or corroded
(3) Condenser shorted or broken down
(4) Magneto weak or crossed
(5) Collector brush worn out or dirty
(6) Distributor brushes worn out or dirty
(7) Collector ring or commutator shorted or dirty
(8) Distributor block shorted or dirty
(9) Secondary winding shorted or broken down
(10) Distributor pencil shorted
(11) Safety gap too low
(12) Distributor out of time with primary circuit
(13) Poor connection between secondary and collector rings
(14) Ground wire or switch shorted.

p. Overheating.

(1) Spark set too late
(2) Poor water circulation
(3) Rich mixture
(4) Poor oil circulation
(5) Oil too thin or cold
(6) Lean mixture
(7) Camshaft set too late
(8) Running at low speed too long
(9) Poor compression
(10) Tight bearings or pistons out of line
(11) Excessive carbon.

q. Poor Compression.

(1) Valves not adjusted properly with respect to clearance
(2) Valves warped
(3) Valves caked with carbon
(4) Valve stems bent
(5) Valves gummed or sticking
(6) Leaky cylinder head, spark plug, or valve cage gaskets
(7) Insufficient oil supply or oil that has been used too long
(8) Rocker arms too light
(9) Valve springs broken or weak
(10) Camshaft out of time
(11) Rings not seating properly
(12) Cylinders scored.

r. Result of Rich Mixture.

(1) Excessive carbon formed in cylinders and on valves
(2) Overheating of motor
(3) Motor will gallop and will not develop proper speed.

s. Result of Lean Mixture.

(1) Motor will back-fire and may catch fire
(2) Will burn valves
(3) Motor will not develop proper speed
(4) Motor will stall or die easily.

t. Result of Too Much Oil.

(1) Will cause engine to misfire by shorting plugs
(2) Will create excessive carbon
(3) Will get on insulated wires and cause short circuits
(4) Will get on cloth-covered parts of plane and cause deterioration
(5) Will vaporize and vapor will interfere with proper combustion, causing effect of too rich a mixture.

u. No Spark.

(1) Primary circuit grounded
(2) Secondary circuit grounded
(3) Grounded ground wire
(4) Switch grounded
(5) Condenser open-circuited or shorted
(6) Magnets crossed.

v. When the Engine Knocks.--Knocks such as the following are caused by various defects in the engine: Loose connecting rod bearings, a rather sharp metallic sound noticeable at low motor speed; loose main bearings, a dull heavy knock accompanied by vibration noticeable when motor is picking up speed or when throttled down; loose wrist pins, a sharp metallic sound very pronounced when motor is throttled down; loose pistons, a rattling sort of sound most pronounced when engine is running under light load. Ignition advanced too far, a very sharp knock without much volume of sound may be stopped by retarding the spark; labor knock, caused by engine running hot or by lean mixture.

w. Oil Pressure Too High.

(1) Adjustment
(2) Bearings set too close
(3) Oil grooves in bearings not deep enough
(4) Oil pipe kinked or bent
(5) By-pass stuck
(6) Too much oil in system
(7) Extra heavy oil
(8) Oil cold or frozen.

x. Rapid Rise in Oil Pressure.

(1) Bearings getting too tight due to overheating
(2) Stoppage in system between gauge and bearings
(3) Too much oil in system
(4) Oil cold or frozen.

y. Oil Pressure Too Low.

(1) Insufficient oil
(2) Regulator not set properly
(3) Oil too thin or cold
(4) Leak in feed pipes
(5) Bearings too loose
(6) Bad gage
(7) Gears in pump worn
(8) Overheated motor.

z. Stromberg Injection Carburetors.--Check carburetor specifications and setting to be sure specifications and setting are for the engine make and model on which the carburetor is installed. Do not change carburetor setting or specification without approval of engine manufacturer or until complete information is available regarding effect of change on mixture ratios and engine operation. Do not change carburetor adjustments until unsatisfactory engine operation has been definitely established as resulting from carburetion.

aa. Engine Will Not Start or Continue to Run After Starting.

(1) See starting instructions for Injection carburetor.
(2) Insufficient fuel pressure. Check fuel pressure gage.
(3) Idle adjustment too rich or too lean. Readjust idle needle.
(4) Air in regulator unit. Remove vent plug in top of unmetered fuel Chamber "D" of regulator unit. Pump fuel until it stands level with plug opening.
(5) Check position of manual mixture control to see that control is not set in idle cut-off position.
(6) Main discharge nozzles sticking open. See that nozzles hold 3 lb.

pressure without discharging fuel. Otherwise, fuel will boil under high vacuum giving erratic metering.

ab. Engine Runs Too Rich or Too Lean at Cruising Power.

(1) Fuel pressure low. Check fuel pump and fuel pressure gage. Clean strainer if pressure will not rise.

(2) Foreign material in cruise jet.

(3) Economizer needle leaking or stuck open. Remove bushing above needle to check for free motion or remove fuel control unit cover body to check needle and seat.

(4) Check automatic mixture control unit setting and bellows. (If carburetor is running rich or lean in automatic position at altitude.)

ac. Engine Runs Too Lean at Take-off or Rated Power, but Satisfactorily at Cruising Power.

(1) Economizer valve binding. Remove fuel control unit cover body and check mechanism for freedom of movement.

(2) Insufficient fuel pressure.

ad. Engine Runs Too Lean or Too Rich at Altitude in Automatic Position, but Satisfactorily at Sea Level.

(1) Vapor separator float needle stuck in closed position. Remove strainer and inspect float for free movement.

(2) Automatic mixture control unit incorrectly set or malfunctioning. Remove this unit from carburetor and check travel and set per instructions.

(3) Manual mixture control valve set in wrong position. Check linkage to manual mixture control lever.

(4) Emergency full rich valve plates open or leaking. Remove valve cover on throttle body and see that slots in plates are open only in emergency full rich position, and that plates do not leak.

ae. Engine Does Not Accelerate Properly, but Runs Satisfactorily with Slow Throttle Movements.

(1) Accelerating pump not adjusted to give required travel. Readjust.

(2) Fuel inlet to acceleration pump clogged at the intake restriction. Remove pump cover, diaphragms and examine.

(3) Discharge nozzle leaking.

(4) Fuel leak into air chamber in regulator unit. Remove air chamber drain plug.

(5) Suction hole to air side of accelerating pump diaphragm closed. Check to see that holes line up correctly.

af. Engine Does Not Shut Off in Idle Cut-Off Position.

(1) Idle cut-off valve washer on mixture control needle not seating properly. Remove plug on side of fuel control unit adjacent to cruise jet to see if washer seats in idle cut-off position. Check control rods for full travel. Check for burr on metering jet.

(2) Economizer needle not seating properly. Remove fuel control unit cover body and check mechanism for freedom of movement.

(3) Check regulator unit for proper operation.